The Journal of

THE ROYAL AERONAUTICAL SOCIETY

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REVIEWS

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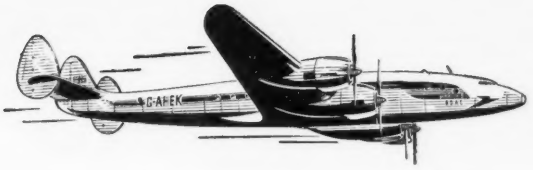

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Although the lift and most of the intertia loads are distributed, it was found possible for the larger Windsor wing to reproduce this by a small number of concentrated loads. Unlike the Windsor and Viking wings, the Viscount wing was placed in the inverted position on the test bed in order to obtain the maximum working space under the wing. The loads were applied to the wing by means of ties, thus avoiding the stability problems incurred by the use of struts. Tension rings were used to measure these loads instead of compression dials.

DETAILED DESCRIPTION OF TEST RIG

The test bed consisted of two Warren girders braced together by top and bottom plan bracing. The head of the bed was a heavy steel plate box carrying the hinge. This hinge unit was formed of spring steel plates interleaved at 90° connecting two heavy steel angles, of which one was attached to the head of the bed and the other to the centre section of the wing. This provided a frictionless hinge which was capable of carrying vertical and horizontal loads besides permitting an angular movement. The whole wing could then be tilted upwards about the centre line of the hinge by means of a vertical lever, attached to the wing, which was rotated by a 40 ton horizontal hydraulic jack. The vertical wing jacks were mounted on the main girders of the test bed and were operated by remote controls to obtain final balance.

The load was applied in increments of 10 per cent. of the calculated ultimate load to 66.6 per cent. and thereafter in increments of 2½ per cent. until the wing broke. This enabled the breaking load to be estimated to within one per cent. Vertical deflections were measured at several stations along the wing by theodolite observation of scales suspended from the leading and trailing edges. The inclination of the root was measured by a clinometer consisting of a plumb line moving over a graduated scale. This scale was attached to the root box and passed down inside the lever but independently of it, thus being unaffected by the deflection of the levers.

To measure the direct and shear loads in the spar, skin and edge members, over 200 electric resistance wire gauges were used at various stations along the wing. Thus a complete stress distribution across the wing cross-section could be extrapolated from these results. The control of the test was simplified by the use of a loudspeaker which ensured that all the operators worked in unison and allowed one man to keep control of the test while keeping all his associates fully informed of the progress of the test. This method of testing has established a technique whereby a test is completed in the space of three hours, compared with at least a full day by other methods.

After the maximum factored load which is likely to occur on the wing in flight had been reached without sign of failure, the load was increased until complete failure took place at 10 per cent. above the maximum design load, a satisfactory figure. Subsidiary tests included stiffness and resonance tests verifying that the wing was satisfactory in all structural aspects.

THE ROYAL AERONAUTICAL SOCIETY

GRADUATE AND STUDENT SECTION

September 1949

VISCOUNT WING TEST

by

D. M. McELHINNEY

Introduction

It is now a requirement of the British Civil Airworthiness Requirements that on every prototype aircraft ordered by the Ministry of Supply which is not of conventional structural design, a destruction test on the major components shall be made. To comply with this requirement the Viscount wing, which has many distinguishing structural features, was tested at Weybridge under conditions approved by the Royal Aircraft Establishment and the Ministry of Supply.

Brief History of Wing Testing

In the early days when aircraft were small and only capable of low speeds, wings were loaded in the inverted position by shot or sand bags distributed along the wings, until failure occurred. This method usually caused the total wreckage of the structure after failure. Since then stressed skin construction has succeeded the old fabric-covered wing and tip deflections, due to increased spans and monoplane designs, are now measured in feet instead of inches. These factors and the necessity for the structure to be readily accessible for inspection under load pointed to the need for new methods of wing testing.

The next method was first introduced by Gerard of the R.A.E. who used hydraulic jacks to apply the loads, thereby making possible a more accurate loading and an immediate release of the applied loads in the event of a sudden failure. The method adopted was to attach the root of the wing to a stiff head and to apply the loads by means of hydraulic jacks through levers or links, the whole system of loads and reactions being self-equilibrating within the test frame. This was actually the method used to test the Wellesley wing at Farnborough. The complicated system of linkage and levers used in this case and the time taken to make the test suggested that a more simple form of loading should be devised. The result was that in the test of the fighter F22/39 only four concentrated loads were applied by hydraulic jacks to give the required loading. The deflections, in this case, were of such an order that with a fixed head the travel of the jacks was sufficient to take up the displacement.

This method was successfully employed but possessed minor defects and hence another improvement was sought for testing the Windsor wing. This had a span of 117 ft. and the calculated tip deflection was nearly 8 ft. so that to accommodate it in a building of reasonable size, when fully loaded and using a fixed head, constituted a major problem. The suggestion was then made that a special hinge unit should be used incorporating root loading levers to enable a small angular movement of the head to be produced, thus greatly reducing the actual vertical movement of the wing. Mr. H. H. Gardner, in co-operation with Mr. B. N. Wallis, was responsible for the design of this new arrangement which proved successful during the Windsor test and also, with a minor modification, for the test on the Viking stressed skin wing. When the Viscount wing was tested in this way the vertical displacement relative to the ground was less than 12 inches, although the calculated tip deflection was of the order of 5 feet. This greatly assisted the operation of the test loading and the measurement of loads and deflections.

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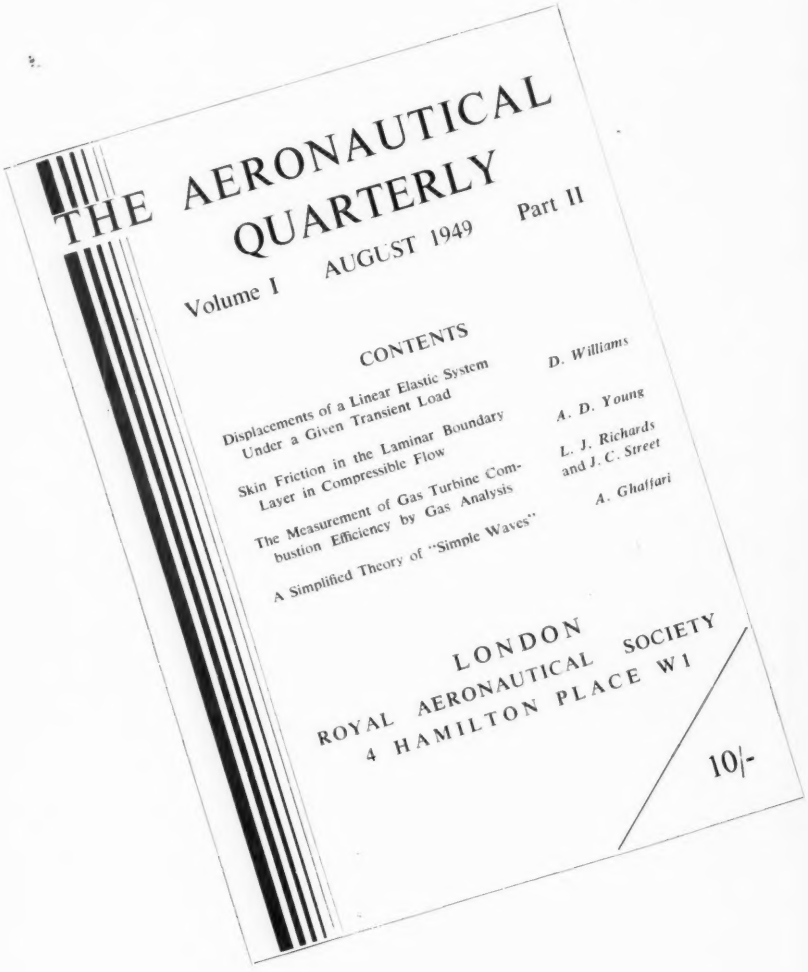
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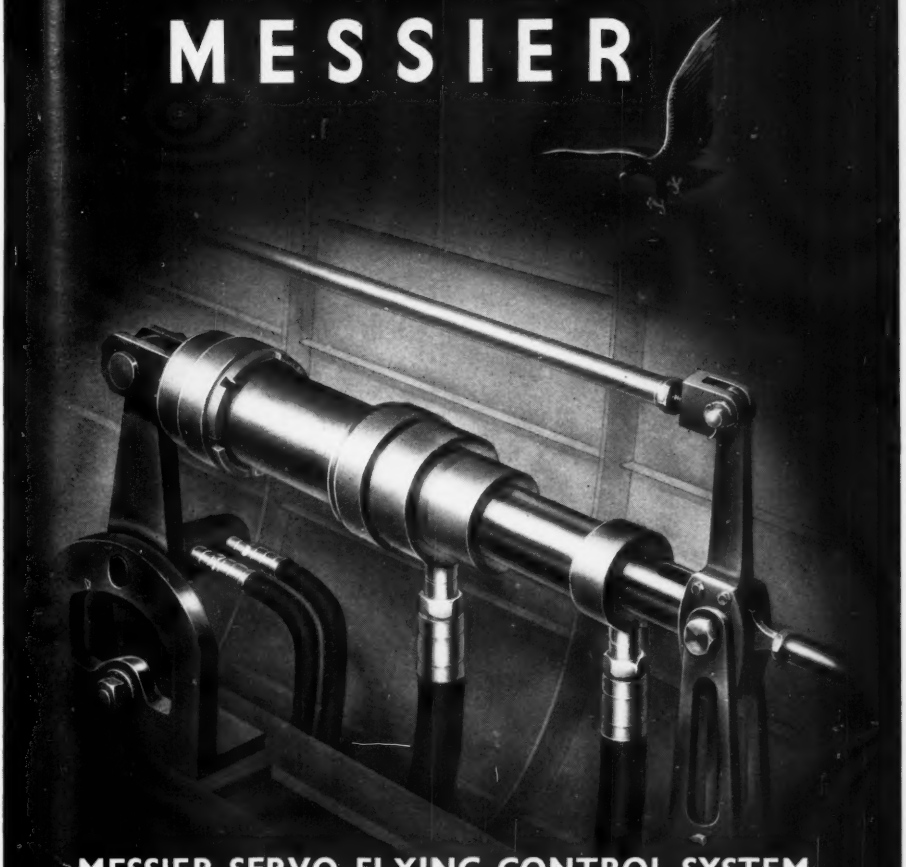

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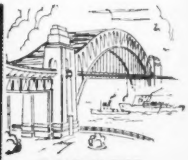

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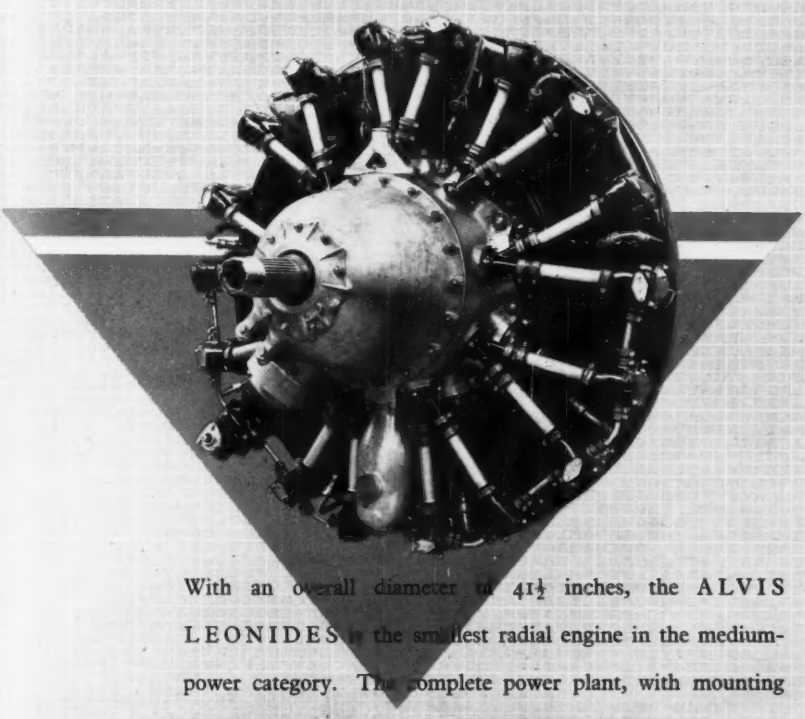

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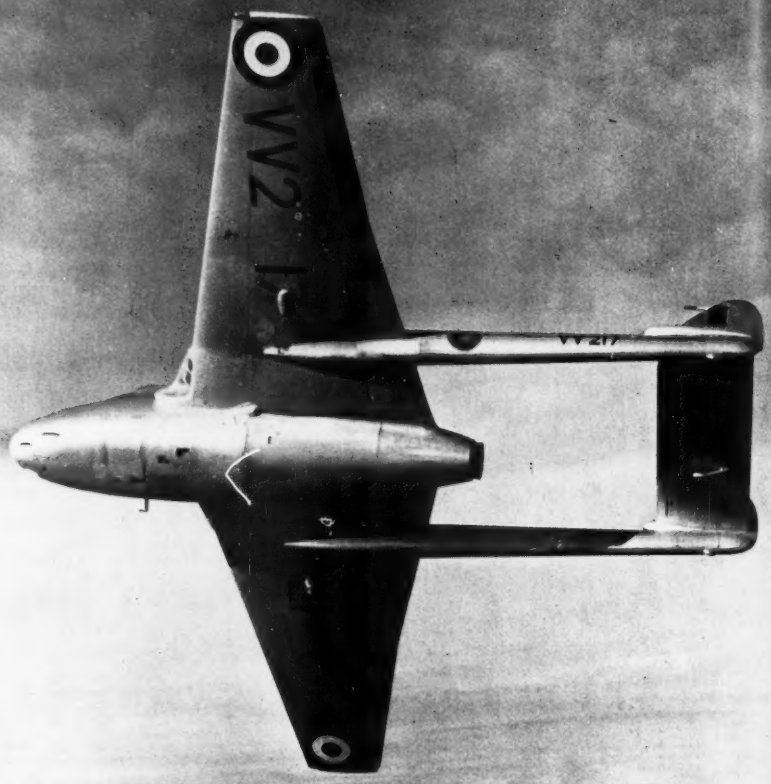

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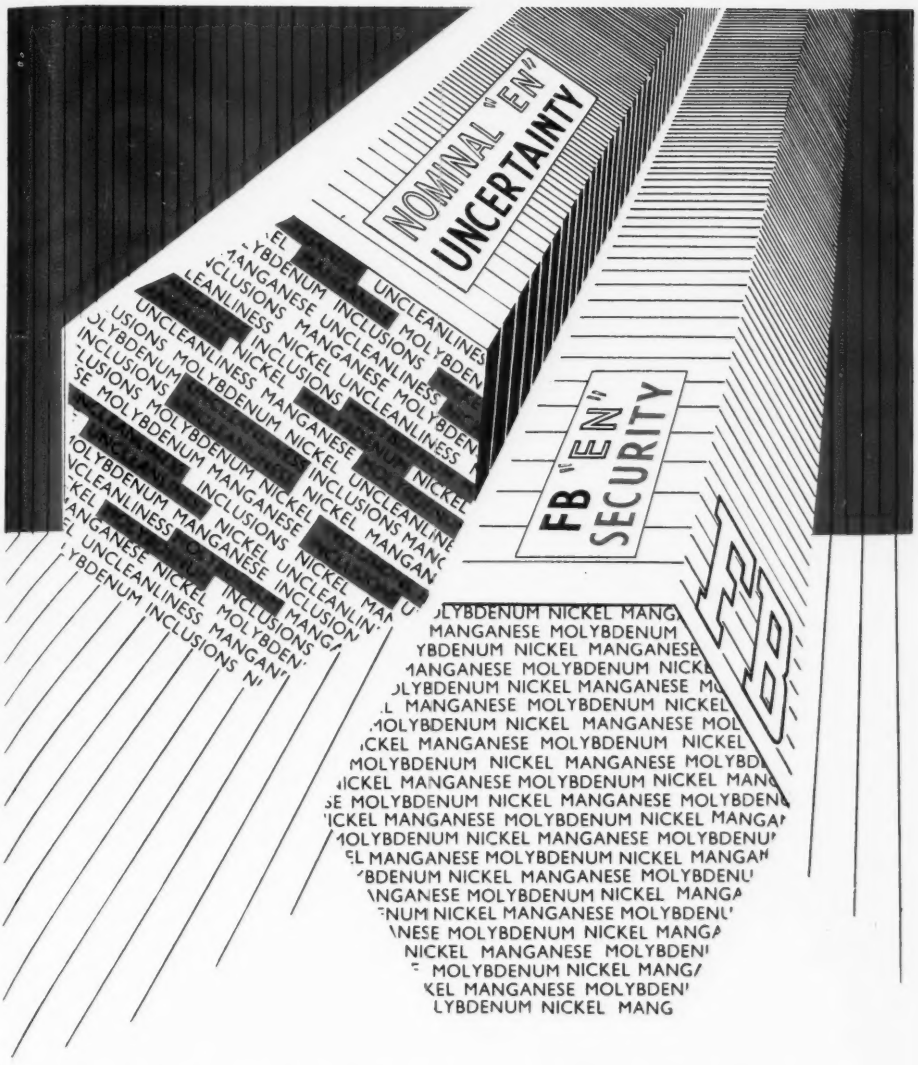

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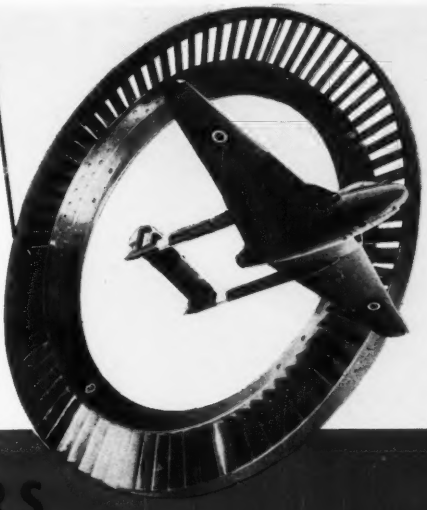

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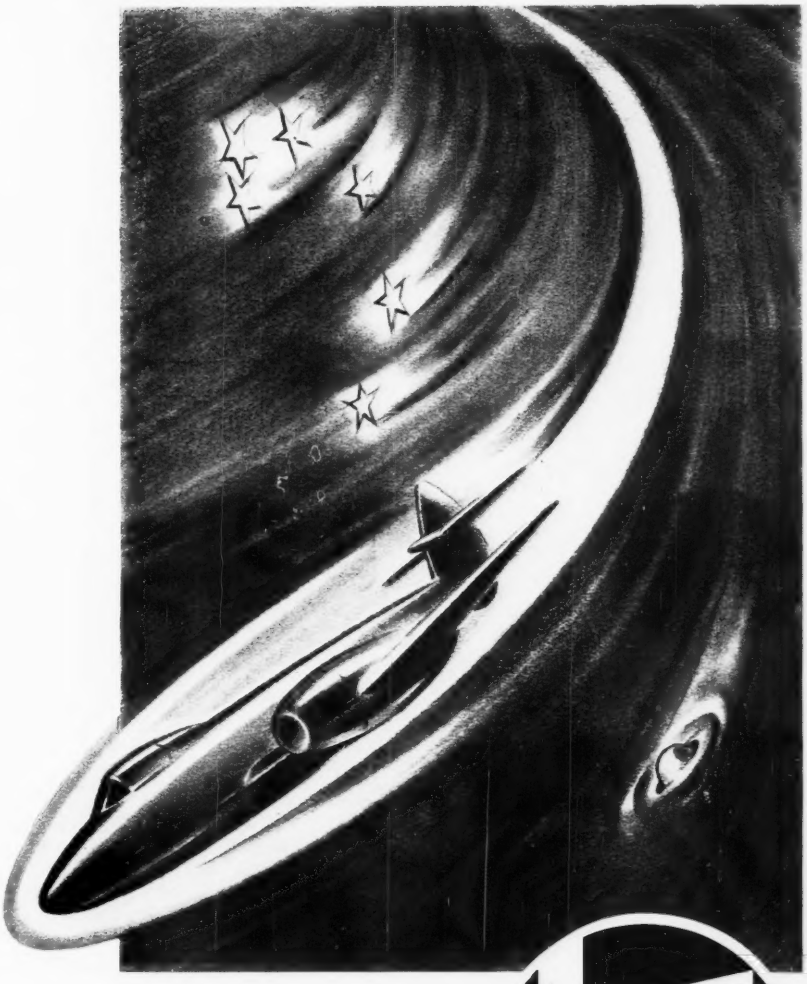

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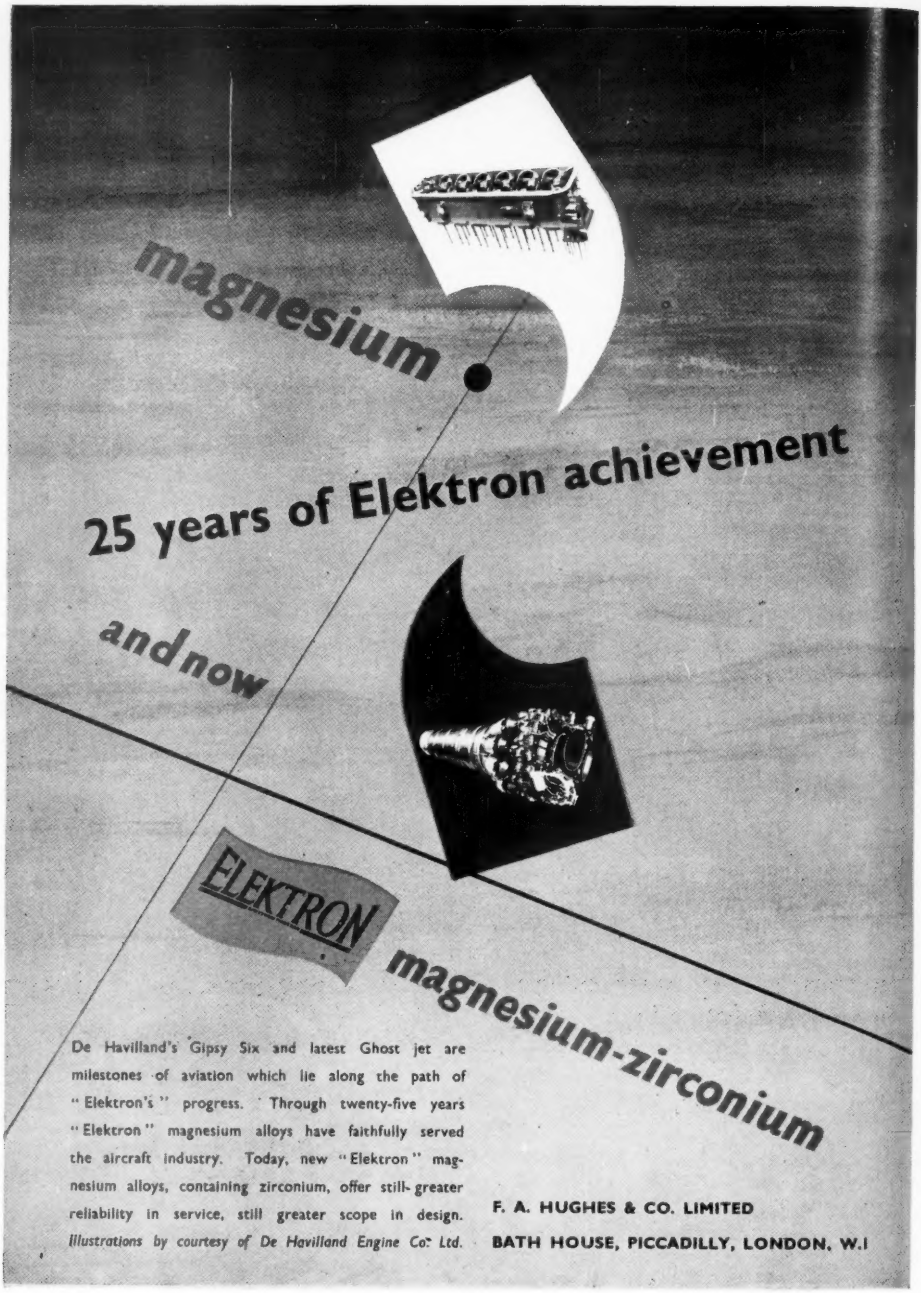

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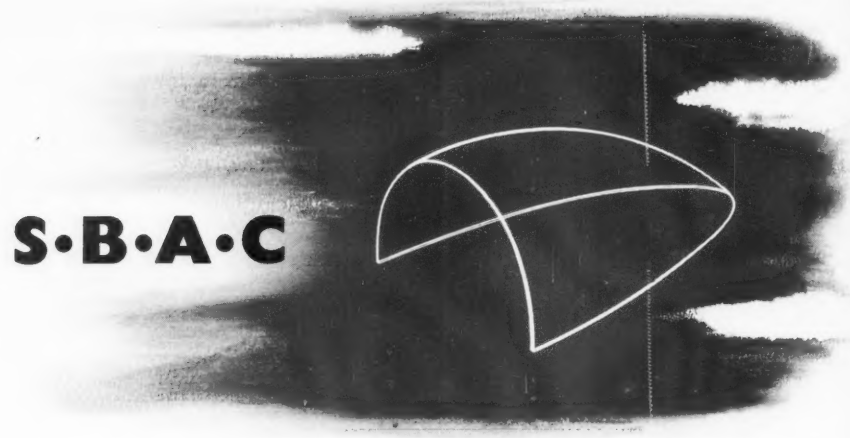

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When Lord Kelvin died in 1907 he left behind him not only a dazzling record of scientific achievement but friends and trusted craftsmen whose hearts and hands had been devoted to those same ideals that had made him famous. Today, still in the service of the firm that he founded, some of these 'old hands' are passing on to a younger generation something of that skill, that passion for accuracy and that single-minded devotion to the subtleties of measurement that made Lord Kelvin one of our great men of science.

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ACCIDENT INVESTIGATION IN RELATION TO AIRCRAFT DESIGN

by

Air Commodore VERNON BROWN, C.B., O.B.E., M.A. F.R.Ae.S.

The 777th Lecture was read before the Royal Aeronautical Society on 7th April 1949 at the Institution of Civil Engineers, Great George Street, London, S.W.1. Dr. H. Roxbee Cox, D.I.C., F.R.Ae.S., F.I.Ae.S., President of the Society, introduced the Lecturer, Air Commodore Vernon Brown, C.B., O.B.E., M.A., F.R.Ae.S., Chief Inspector of Accidents, Ministry of Civil Aviation.

THROUGH the ages accidents have happened in all forms of transport. We find references to them in legends and in historical records and they seem to be part of a price that must be paid for progress. During the past hundred or so years, each British government of the day has laid upon the minister concerned an obligation to have such occurrences investigated in order that remedial action might be taken and to safeguard the fare-paying public from the machinations of irresponsible people—in other words, for *safety's* sake.

In the word " safety " lies the story of the effect of accidents on design. In an aircraft the omission to lock a nut on a bolt would almost certainly reflect on manufacture or maintenance and would be unlikely to require technical action, whereas the breaking of a bolt might well need consideration regarding its strength. To use a larger bolt would at once introduce a design feature. If the wings of an aeroplane break during a pull-out and a static test shows they are not up to the required strength or that the estimated factor of safety is too low, it is the designer's job to make them strong enough. But the information about the circumstances in which any such accident occurred must be collected; the primary fracture must be determined.

It is for the purpose of finding causes that accidents are investigated, and if it were possible to avoid the attributing of blame the task would be far easier. But to say that an accident was the result of the aircraft flying into a hill in conditions of bad visibility, or that the cause of a crash was the structural failure of a wing in the air would satisfy nobody. So long, therefore, as air accidents happen so long must there be an organisation to deal with them, and until the aircraft designer can be sure no feature of his work has caused, or contributed to, an accident, he must accept the situation that an investigation organisation is necessary and make what use he can of the information that becomes available to him.

During the late war, and particularly in its earlier days, aircraft were often literally bought off the drawing board. Thus, structural defects were sometimes inevitable and teething troubles could not be entirely eliminated before a type was in production. Such a situation must always arise in time of hostilities and has to be accepted as a war risk in face of the paramount necessity of gaining ascendancy over the enemy. It is fortunate that in peacetime the lack of urgency makes for greater safety.

So far as accidents are concerned there has always been a close liaison between the Ministries. Ever since the technical departments of the Air Ministry were removed to form the nucleus of the Ministry of Aircraft Production, now the Ministry of Supply, contract action in respect of R.A.F. types has been the responsibility of the latter, based on the requirements of the former. This is also true of the Admiralty and to a certain extent the Ministry of Civil Aviation. It has followed logically that almost every new type has been watched over by the Ministry of Supply from the design to the production stage. The cause of an accident, therefore, has been of the utmost importance to that Ministry, quite apart from any administrative or flying faults that have been

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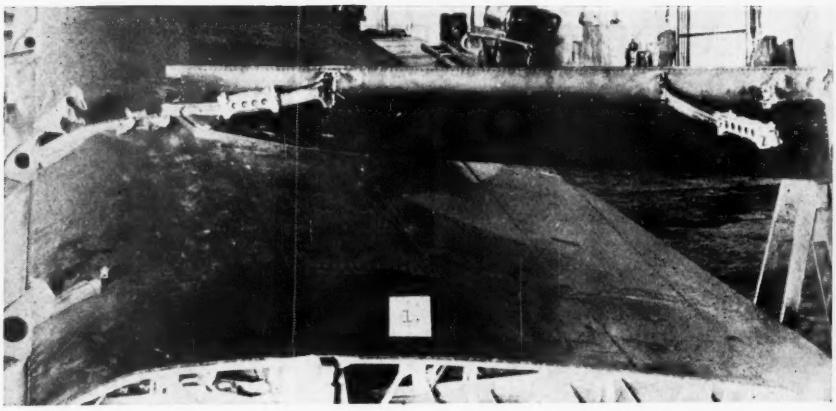

Fig. 1.

brought to light during the investigation. Thus, in respect of Service aircraft, the Accidents Investigation Branch has maintained the closest possible connection with the Ministry of Supply and, in particular, with the Royal Aircraft Establishment at Farnborough when any technical factor has been found to be of importance.

For civil aircraft the Air Registration Board normally takes the place of the M.O.S. or, at least it is on an equal footing so far as the passing of information is concerned, and although there is a direct contact between the Accidents Investigation Branch and the Air Registration Board, the Air Safety Directorate of the Ministry of Civil Aviation shares with the Board the responsibility for follow-up action. Often there is no direct recommendation by the A.I.B. but only the pointing out of undesirable features. Moreover, it is not always possible to introduce drastic changes on the evidence of an isolated case, but should there be even two or three accidents which present similar technical aspects, it becomes obvious that something must be done immediately.

The effect of any investigation may be the calling of a meeting or the discussion of the matter on paper. If an important technical fault has been disclosed, urgent action is inevitable and the former course is usually followed. Thus, the result is likely to be immediate insofar as the safety aspect is concerned, although it may in that respect only involve modification action. The apparent effect on design will naturally come later. Nevertheless, once fundamental requirements have been accepted the finer points of design and the raising of standards quickly follow as the obvious results of competition and free enterprise, although the fact that an accident or a series of accidents had anything to do with the matter is probably soon forgotten.

Necessity is the mother of invention and the Design Requirements for Aeroplanes, A.P. 970, and the A.R.B. Civil Airworthiness Requirements, are the results of years of experience gained the hard way. Looking back over the A.I.B. records it is difficult to decide which of those thousands of requirements to choose as examples, since so many of them have been written as the direct or indirect results of accidents. In almost every chapter some safety precaution can be detected, the reason for which may now seem obvious but which was originally introduced after the investigation of a crash.

It has not been easy to decide how to illustrate the effects of accident investigations on aircraft design. In a problem of this kind statistics are not very helpful; even were that not the case, the security aspect of the use of Service statistics makes it an undesirable form of approach.

Now accident investigation shows that in the failure of the human element lies the majority of causes. Nevertheless, many of the human breakdown cases touch so closely upon the technical aspect that the relationship between these two classifications must always be carefully examined. For example,

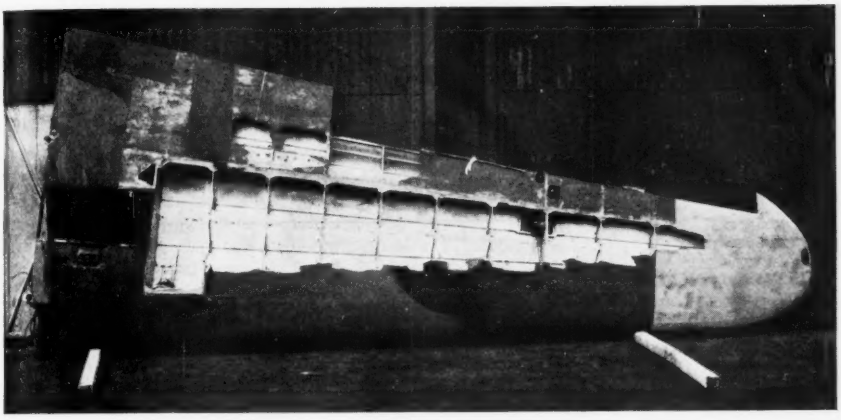

Fig. 2.

it may happen that if technical equipment had been differently constructed or differently used no accident would have occurred. Thus, a breakdown by the pilot in his cockpit drill might not have happened had the cockpit been differently designed, bearing in mind the layout of instruments and controls and the "fatigue" factor bound up so closely, and yet so undefinably, with the discomfort of prolonged immobility in conditions of noise and low temperature. It has seemed best therefore to select from the A.I.B. records certain well-defined examples of how the technical information obtained has been applied to the rectification of major troubles. In doing this it has been difficult to avoid reference to specific types and it has been necessary to consider the discussion of individual cases, or a series of such cases, without giving offence to the firms responsible for the design and construction of particular airframes, engines and accessories. An attempt has been made to avoid doing so, and if the veil is sometimes thinly drawn the author asks forgiveness. Like Peter Quince—"If we offend, it is with our good will."

STRUCTURAL FAILURE IN THE AIR

Although structural failures have often occurred during aerobatic manœuvres, or when high *g* has been applied, as in a too rapid pull-out, the majority have happened after loss of flying control. This loss of control has always been a formidable problem, particularly if associated with turbulent conditions in cloud. It may be that one of the chief factors is pilot's skill. The most obvious way of tackling that aspect of the question is to simplify aircraft and to design them with the easing of the pilot's task in the forefront of the conception, without lessening the required safety factors. But let us consider some cases the blame for which cannot be laid upon the pilot.

NOSE RIBLETS

In an early design of fabric-covered biplane several cases of wing failure occurred as the result of the collapse of the leading edge nose riblets. In order to fill the fuel tank it was necessary to stand on steps and lean over the wing. A foot rest was also provided on one side of the engine. A weakening of this part of the leading edge was sometimes caused by people grasping the plane to steady themselves when reaching the tank filler cap and sometimes by leaning heavily, or even kneeling with one knee on this part of the plane close to the root end fitting. The immediate cure was the strengthening of the wing at this point, but in due course plywood was used for the nose piece in front of the main spar. Nowadays plywood has almost entirely superseded fabric in this type of wing.

SLATS

In one class of structural failure an important consideration is the low speed wing stall, recovery from which is the more

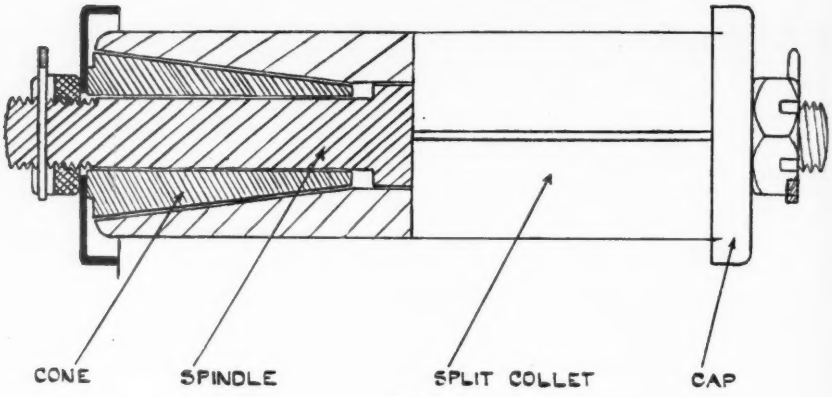

Fig. 3.

difficult at low altitude. It will be remembered that many years ago slats were used on certain of the smaller kinds of aircraft as a safeguard against this particular trouble. Generally, their use was followed by a reduction in the slow stall accident rate, especially at schools. But people were apt to think of the slat as a device which operated according to the speed of the aeroplane, whereas actually it opens as a function of the angle of attack (see Fig. 1). The result was serious damage to, and sometimes the complete disruption of, the mainplane when the slat moved forward violently in some high *g* manœuvre, such as a too quick pull-out from a dive after a loop. Its introduction into larger and faster aircraft at the beginning of the war caused several structural failures in the air. The palliative was the sealing up of the slats and after 1941 their use in new types was entirely dropped.

Skin failures

Cases occurred of the mainplane plywood top skin coming off in the air. In a certain type of aircraft a tread mat was provided to enable the fitters to service the engine without walking on the weaker parts of the wing (Fig. 2). Investigation of accidents of this kind proved that the mat was too small and that fitters were treading on the wing between the main ribs or were damaging it with their toe caps when working in a kneeling position. Enlargement of the tread mat and a strengthening of the plane in this region put an end to the trouble. In later editions of the same type of aeroplane there has been no recurrence of this.

Tensioning of control cable circuits

During the war a large number of structural failures to a certain fighter type were attributed to aileron instability and it was recommended that the following should be introduced:

(*i*) an aileron up-float limit;
(*ii*) accurate tensioning of the aileron control cable circuit.

A subsequent and decided improvement in the accident rate—1 in 16,000 hours to 1 in 82,000—corresponded with the introduction of this instruction.

Accurate tensioning of all control cable circuits is now standard practice for Service aircraft.

In the case of civil aircraft with control systems incorporating cables, the designer must declare the tension at which the cables are to be rigged on the ground in order to avoid undue slackness under all likely extremes of temperature and humidity, and proper allowance must be made in the design of the system for such a degree of tension.

The case of a special type of attachment bolt

An attachment joint which had given good service in several types of aircraft manufactured by a certain firm failed in the air on a new product. When a wing breaks it is unusual for the primary failure to

occur at the attachment fitting and special attention was consequently given to that part (Fig. 3). In this system of joint, spindles were used running through cones. Nuts at the end of the spindles were used for pulling the cones into split collets. It seemed possible for a heavy handed fitter to pull the nuts up until the threads were damaged. As the collet was subject to varying loads the cones would then tend to move out and shear the nuts and split pins.

On a test it was found that by using excessive force on a regulation spanner it was possible to so damage the nut on a $\frac{5}{8}$ spindle that the failing load was reduced from an average of 6.4 tons for a new nut to 1.7 tons. The cause of the accident, without doubt, was due to faulty assembly, but certain design features were altered to avoid a repetition. As soon as the cause was discovered in this case all units using that type of aircraft were signalled to examine the fitting at the next daily inspection. No less than eight defective attachment bolts were discovered on the first day.

The Spiral Dive

During the year 1938 eight serious accidents occurred involving a certain monoplane trainer. From the evidence collected during the investigation the following undesirable flying characteristics were revealed:—

Climbing—During the climb the aeroplane yawed to the right and required left rudder to keep it straight.

Gliding—During the glide the aeroplane yawed to the left.

Diving—During a dive the aeroplane tended to yaw to the left and under this condition a backward movement of the control column had the effect only of steepening the dive, for unless right rudder was applied to correct the yaw, the elevators were inoperative. When the yaw was corrected, recovery from the dive was normal.

Spinning—Contrary to accepted principles, the aircraft would spin off a straight stall without any yawing couple being applied. The tendency for this aircraft to remain in a dive further complicated the recovery from a spin.

As a result of investigation, wind tunnel tests and full-scale trials, major design changes were made, increasing the effective area of fin and rudder. With these changes embodied, no further accidents of this description occurred.

Rudder Over-balance

An unfortunate series of accidents happened on an important four-engined aircraft involving loss of control and subsequent structural failure. The majority of these occurred at night or in cloud. One of the many features of these accidents was that if the aircraft were permitted to skid in a dive the inner wing tended to drop and the nose to follow it. The speed then increased and use of the elevator tightened the resulting spiral without reducing the speed. In this respect the cases were similar to those of the monoplane training type, to which reference has already been made.

To recover from the spiral dive was not difficult so long as the skid was trimmed off by means of the rudder *before* aileron was applied. Unfortunately, loss of control from this cause was frequently aggravated by engine or propeller failure. The underlying cause of this characteristic was the large change of directional trim with power and speed. The outcome was the introduction of larger control areas, particularly of the fin and rudder areas.

Similar characteristics later showed themselves on a type of quite different construction and gave rise to the introduction of a dorsal fin.

Elevator Control

In another important four-engined aircraft a tendency to nose into a dive early manifested itself. Very high stick forces were required for recovery from high speed dives. The resulting crashes were characterised by the similarity of the elevator failures. Early in 1943 it was suggested by the Royal Aircraft Establishment that these characteristics might be caused by distortion of the elevator fabric. Tests were therefore made with metal elevators, with the astonishing result that the pull force on the stick necessary to prevent increase of speed for a steady dive of 360 I.A.S. with trim for 220 I.A.S. was reduced by about 50 lb. This actually made a slight push force necessary when the C.G. was near the forward limit. It became possible to recover from dives up to the aircraft's limiting speed without recourse to the trimmer. It is

significant that all the subsequent types of aircraft built by that firm have had metal elevators.

Strength tests

To illustrate the result of investigation by the A.I.B. being followed to a satisfactory conclusion by the R.A.E., the following quotation from an A.I.B. report is of interest:

> "All five accidents investigated by this Branch appear to have a common feature in the instability failure in the mainplane front spar compression boom . . . . ."
>
> "It is recommended that a wing test to destruction should be carried out at the R.A.E. under loading conditions to be agreed between the manufacturers and the R.A.E."

The original design requirements called for a factor of 9 at 12,000 lb. The first pair of wings was tested at the R.A.E. with load distribution for the high speed pull-out condition. Failure occurred at 88 per cent. of the calculated design load of 7.2 x 13,900 lb—equivalent to a failure at a factor of 6.3. The failure of the wing in test was typical of the failures which occurred in these flying accidents.

With this information the manufacturers were put in possession of the necessary data for the re-design of the type—a type which afterwards gave several years of satisfactory service.

Propellers

During the investigation of certain accidents which had been caused by the failure of wooden propellers it was found that a number of them were either breaking, or developing defects, as the result of centrifugal loads in the region of the tip sheathing (Fig. 4). Several of these cases showed that the glue had been made too thin and had probably been too dry when the joint was actually pressed together. Alternatively, if the glue were not too thin the joint had been pressed together before the glue had become tacky, with the result that most of it had been squeezed out. The majority of these accidents resulted from failure of a scarf joint after a new tip had been fitted (Fig. 5). Other cases were brought about by rivet failure. After attention had been drawn to these troubles manufacture and repair processes were changed and the number of wooden propeller failures reduced to insignificant figures.

FIRE IN THE AIR

In the early days of the war with the increase of operational and non-operational flying there was a large increase in the number of fires in the air. In nearly every instance these fires resulted in a serious accident, and it was generally agreed that the existing fire fighting methods and aircraft equipment were not effective with high powered modern engines. It did not seem to matter whether the fire developed slowly, following a minor failure such as a leakage from a pipe or union, or rapidly following a major engine failure; in most cases the final result was catastrophic (Fig. 6). Collapse of a wing had followed the first appearance of a boosted mixture fire in as short a time as a minute and a half.

Briefly, it was discovered that fires were usually caused by

(*i*) Break-up or partial failure of the engine, causing leakage of oil, hydraulic fluid or fuel air mixture (Fig. 7).

(*ii*) Leakage of inflammable fluids through faulty pipes or joints.

(*iii*) Location of combustible pipes or leads close to the exhaust system, or bad location of oil or fuel breather pipes combined with over-filling of oil tanks.

(*iv*) Exhaust pipe failure or displacement allowing flame to impinge on combustible material.

The source of ignition was usually the exhaust system, but in some instances inadequately flame-proofed electrical equipment was responsible, such as a generator or magneto.

In November 1942 an amended anti-fire drill was issued, which in some respects was directly opposite to what had previously been accepted as the correct action. For example, it had been the practice in the event of an engine fire in the air to open the throttle as a remedy. This action was reversed because in the majority of fires opening the throttle with a supercharged engine supplied the fire with boosted mixture or, if the oil or fuel system were ruptured, supplied the fire with inflammable fluids. So feathering the propeller and stopping the engine *before* operating the fire extinguisher became an essential first step to extinguishing a fire in the air.

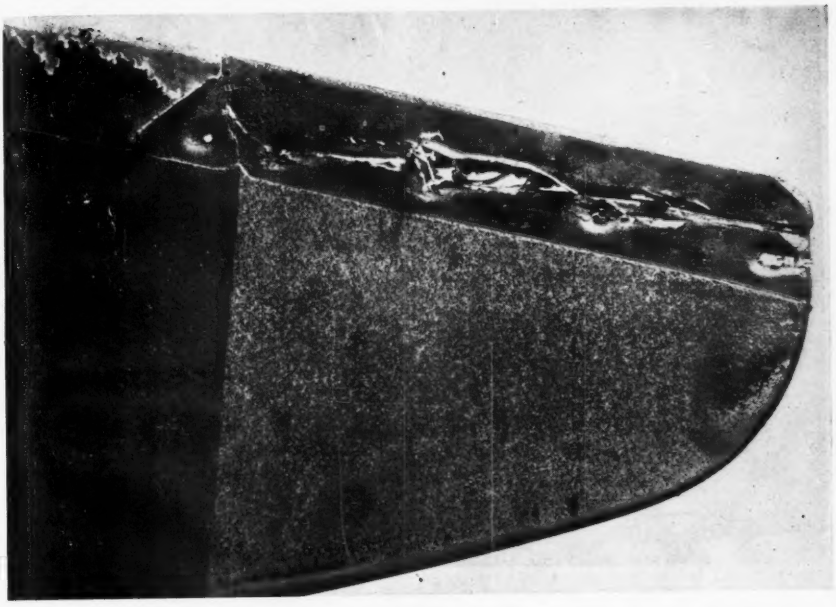

Fig. 4.
Specimen of tip sheath failure.

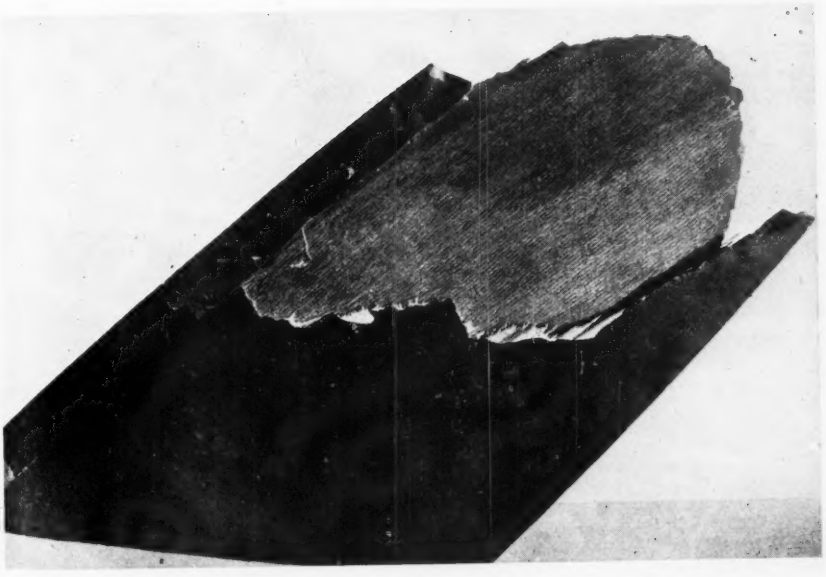

Fig. 5.
Specimen of scarf joint failure.

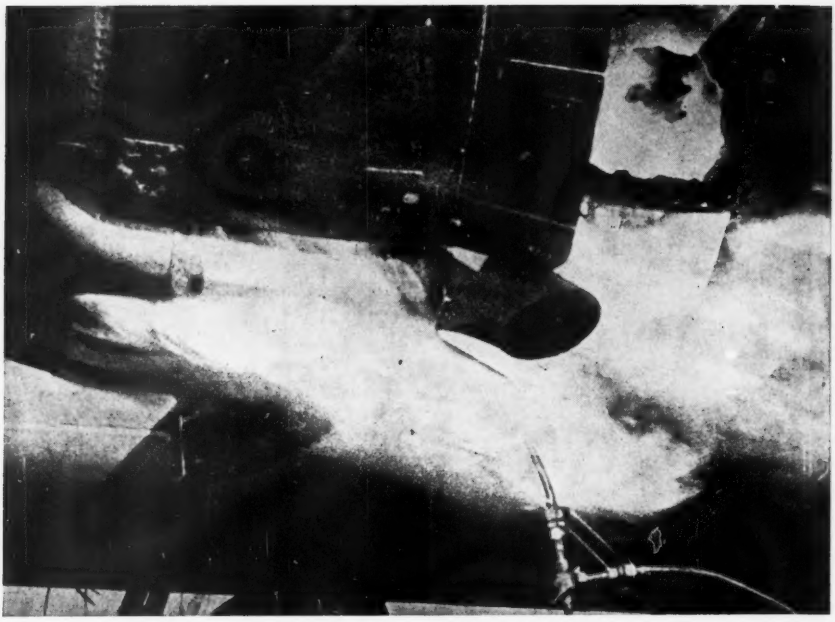

Fig. 6.

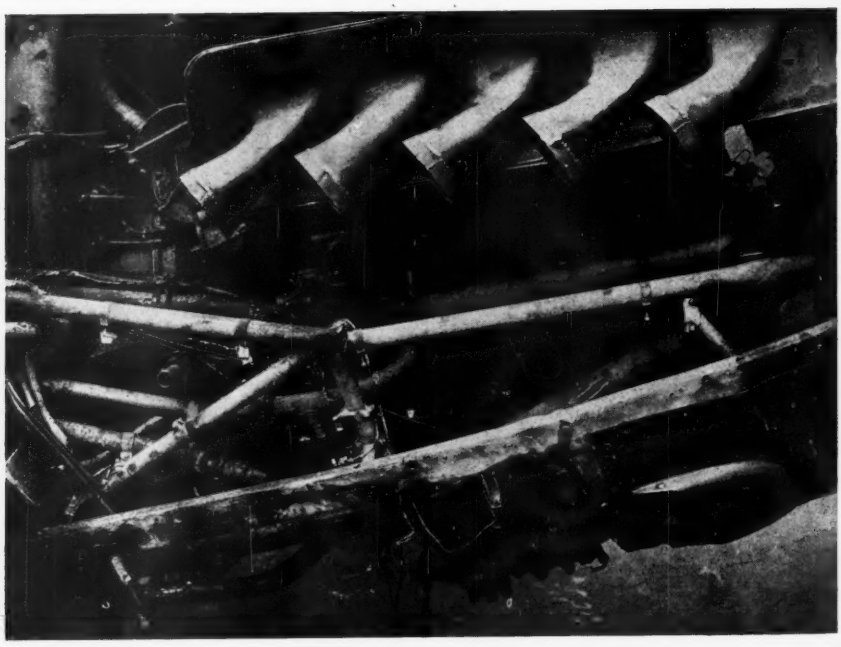

Fig. 7.

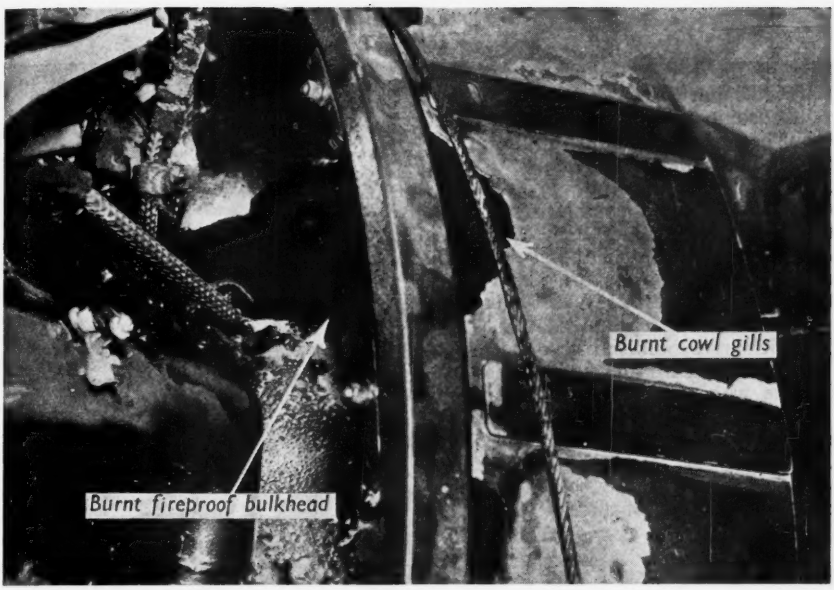
Burnt cowl gills
Burnt fireproof bulkhead

Fig. 8.

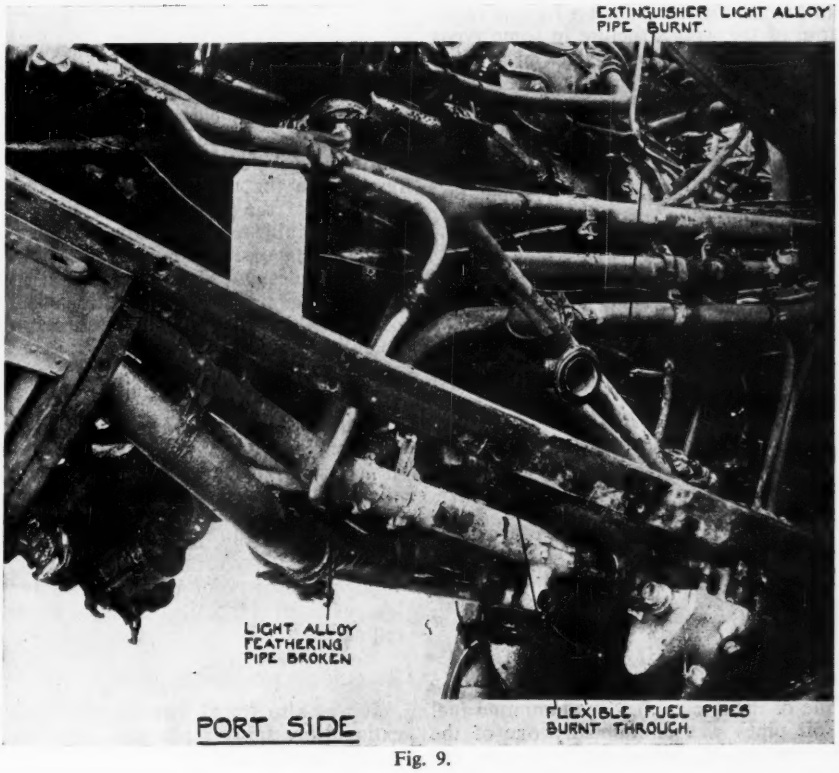
EXTINGUISHER LIGHT ALLOY PIPE BURNT.
LIGHT ALLOY FEATHERING PIPE BROKEN
PORT SIDE
FLEXIBLE FUEL PIPES BURNT THROUGH.

Fig. 9.

Done in the correct sequence, the new drill proved immediately successful and has paid handsome dividends ever since. It has now become a standard anti-fire action in both military and civil flying.

Arising out of numerous investigations into fires in the air, a combined report by members of the A.I.B. and R.A.E. staffs was issued in August, 1943 and given a wide circulation. In this report, known as CH.404, many causes of fires were given and a number of recommendations were made which have been put into effect. On the work and results of the investigations during the war years, the British Military and Civil Airworthiness Requirements regarding fire precautions are largely based.

Here are a few reasons for the many design changes that have been introduced to improve the safety of aircraft against the fire hazard.

Power plant bulkheads

It was found that in the event of an engine fire in the air the main reason for the rapid collapse of the wing structure in some types of aircraft was caused by the lack of suitable protection to the main spar. Moreover, a number of aircraft had no fireproof bulkhead at all, while others were equipped with what was commonly supposed to be a fireproof bulkhead but really consisted of one thin sheet of aluminium with numerous holes through it for the engine pipe lines and controls, and the like. This type of bulkhead was often quickly burnt through (Fig. 8).

Because of these failures a fireproof bulkhead, usually of stainless steel sheet and which had withstood a rigid fireproof test successfully, was accepted as an essential requirement.

Engine cowlings

Investigations also showed that an engine fire could quickly destroy light gauge aluminium cowlings and permit the flames to attack the wing structure. Light gauge steel sheet cowlings were recommended and a number of these are now being embodied.

Fire-proofing of oil and fuel pipes

The burning through in a very short space of time of flexible rubber or aluminium fuel and oil pipes was undoubtedly one of the main causes of some fires in the air

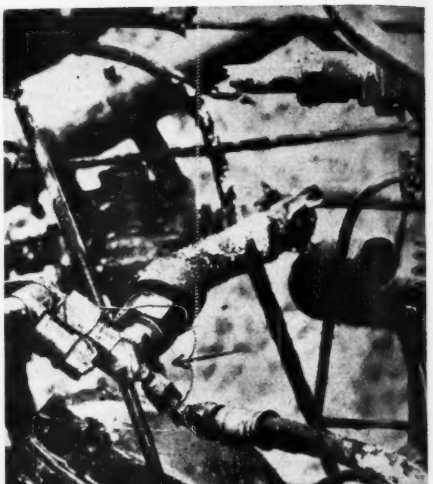

Fig. 9*a*.

becoming quickly catastrophic. Damage to the essential feathering pipe line and feathering oil pump, in many instances, was responsible for the inability to feather the propeller of the engine on fire (Fig. 9).

Considerable research has gone into the fire-proofing of fuel and oil pipes, now an essential design requirement for power plants, and the feathering mechanism has been suitably protected or moved out of any potential fire zone.

Fire extinguisher spray piping

It also became apparent that extremely high temperatures existed during engine fires in the air. The melting in the early stages of the fire of the aluminium fire extinguisher spray piping rendered the extinguishing system practically useless, often before it could be operated by the pilot.

High melting point material, such as stainless steel, is now called for as an essential requirement.

Re-run of the spray piping

It was also found that the run of the fire extinguisher spray pipes and rings was not satisfactory and that the extinguishing

medium was not being directed to the seat of the fire. Experience, borne out by a number of full-scale fire tests, showed that additional spray rings and bottles were required, and these are now an essential requirement in most military and civil aircraft.

Insecure Unions and Leaking Inflammable Fluids

One of the main causes of engine fires in the air was a broken or insecure pipe or a loose connection (Fig. 9A). Vibration is one of the main causes of fatigue failures or of loose connections, and there is no doubt at all that an inadequately supported pipeline or the absence of a positive locking device on fuel and oil pipe unions was the primary cause of several fires. During the war a large number of unions and pipe connections in the power plant were not wire locked (Fig. 10). This was due to a production easement concession owing to the very large breakage rate of $\frac{1}{16}$ in. drills used by female operatives; this size of drill was, at the time, in very short supply.

Considerable research and experiment was done by the R.A.E. and locking wire in stainless steel proved, after all, to be generally the most satisfactory. At the end of the war locking wire was re-introduced and the locking of all unions and nuts of pipes carrying inflammable fluids in power plants is now an essential requirement. Since the war not a single fire has been investigated by A.I.B. which was caused by an insecure or leaking pipe union which had been wire locked correctly in the first place.

Flame-proofing of Electrical Equipment

The ignition point of some of the fires investigated remained obscure until it was discovered that the cover for the generator brush gear was of aluminium with large perforations. Often the generator was situated in a position where leaking petrol could drop on to it (Fig. 11). Sparks from the generator brushes formed an adequate ignition point for a fire. Some magnetos also suffered in this respect. The vents for the distributors were usually of fine mesh wire gauze and were at that time accepted

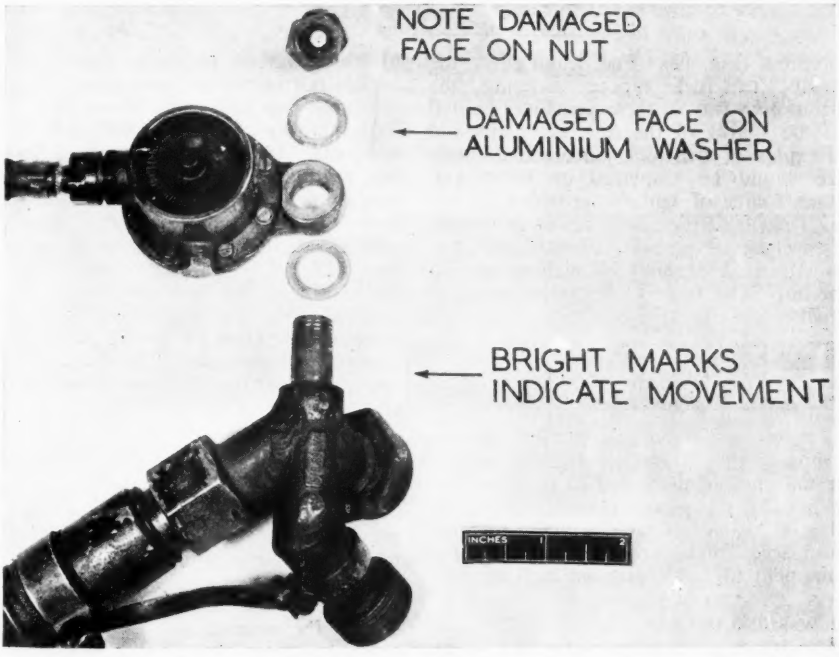

Fig. 10.

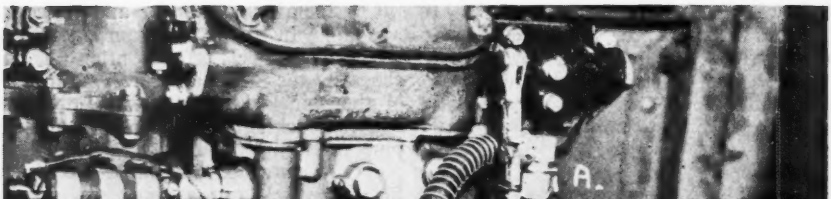

Fig. 11.

as fireproof (Fig. 12). Fuel leaking into the magneto, or fuel vapour entering the distributor by way of these vents was ignited from the sparks of the distributor rotor, a mild explosion then took place and the wire gauze would be displaced or burnt and another source of ignition provided.

As a result of these weaknesses in design, the covering of generator brush gear has been improved or entirely enclosed and a flame-trap vent is now embodied in most magnetos.

Fuel and oil shut-off valves

It was noted during some investigations that the fire in the air had reached serious proportions because of the inability to shut off inflammable fluids feeding the engine, once the fire had destroyed or damaged the pipe lines in the power plant.

Shut-off valves for all pipes carrying inflammable fluids are now an essential requirement for multi-engined civil aircraft.

Fire warning devices

Not many years ago the pilot of a multi-engined aircraft had no device in the cockpit to warn him or his crew that a fire had broken out in one of the engines. This lack of initial warning was responsible for a large number of disastrous fires in the air accidents. It was therefore urged that the first requirement in connection with limitation of fire is an efficient and well placed flame detector. The longer a fire burns undetected, the more difficult it will be to extinguish. Considerable research went into the making of the detectors now fitted (Fig. 13). A fire warning device is now an essential requirement in all multi-engined aircraft and consists of a detector which operates a warning light on the pilot's panel (Fig. 14).

Wing root sealing by a bulkhead

Structural damage caused by an engine fire in the air has not always been the primary cause of the accident. Accidents have occurred in which the pilot has lost control because of smoke and fumes entering the cockpit and rendering it impossible to control the aircraft.

Investigations showed that in some multi-engined aircraft the wing roots were not

sealed and that from any fire which existed at the engines, or in the wing, the smoke could enter the fuselage and cockpit (Fig. 15).

As a result of the recommendations made, new aircraft today have the wing roots sealed so that no fumes can enter the cockpit in the event of a fire in the air.

Fig. 12.

Fires caused by badly positioned oil or fuel breather outlets

A number of fires occurred because of the ignition of oil, or fuel, by the exhaust pipe or gases where this oil or fuel had been drained or vented from the engine and allowed, through bad positioning of the vent outlet, to impinge on the exhaust system.

Re-design action was taken to eliminate this risk, and it is now an essential design requirement to route all vents and drains of inflammable fluids so that the risk of ignition from the exhaust system does not arise.

Fuel and oil vents

In 1944 several fires in the air occurred in a certain type of aircraft in an epidemic sequence. All these happened during, or immediately after, an aerobatic manœuvre. The fabric covering from the underside of the fuselage and flaps usually caught fire first.

Investigation showed that during aerobatics fuel escaped from the fuel tank vent outlet situated in the centre line of the fuselage, between and about 30° behind the exhaust extension outlets. The amount of fuel vented during flight varied, but during a 20 minute test flight 8½ fluid ounces were collected. It was also noticed during these investigations that the belly of this particular type of aircraft was in almost every instance saturated with oil. It was then discovered that the engine crankcase oil breather was positioned two ft. forward of the bulkhead and level with the exhaust pipes. Any oil emitted from this breather would thus be

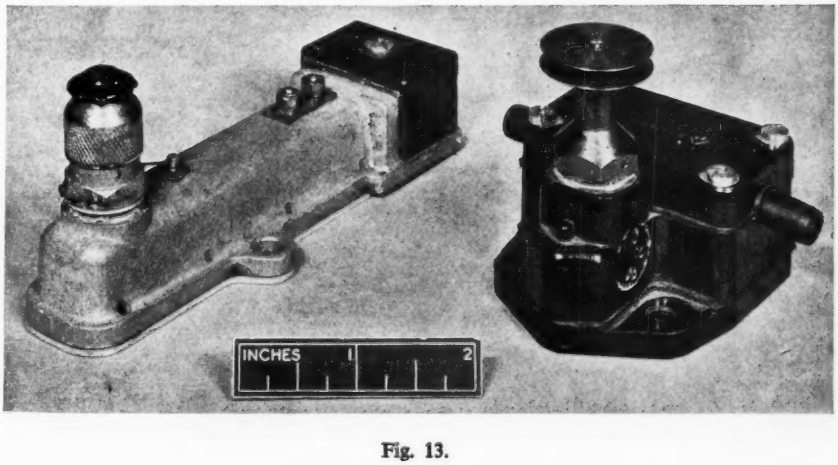

Fig. 13.

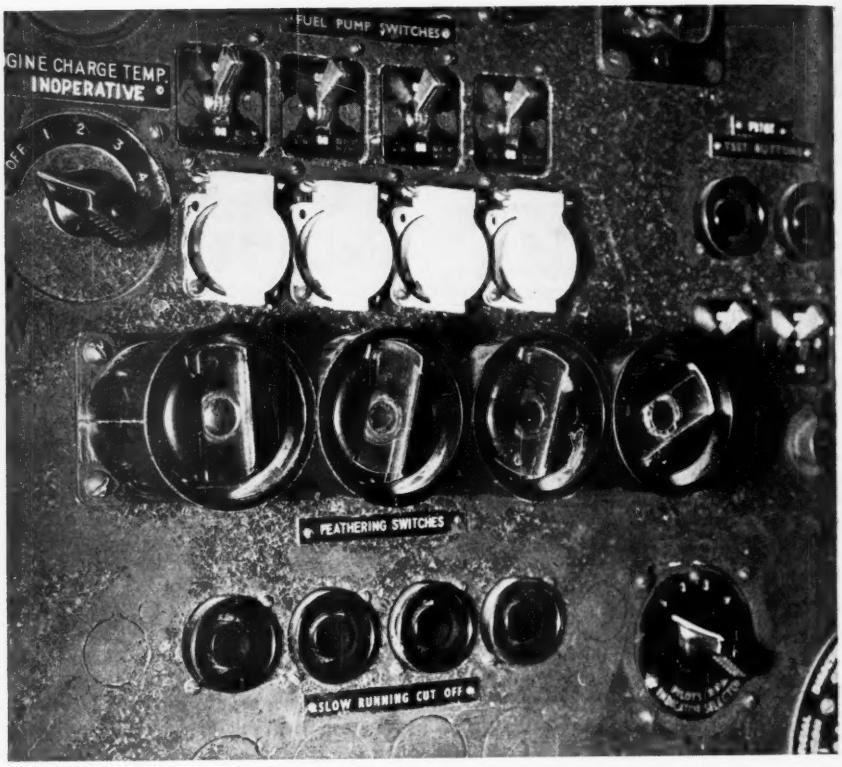
FUEL PUMP SWITCHES
GINE CHARGE TEMP.
INOPERATIVE
OFF 1 2 3 4
FEATHERING SWITCHES
SLOW RUNNING CUT OFF

Fig. 14.

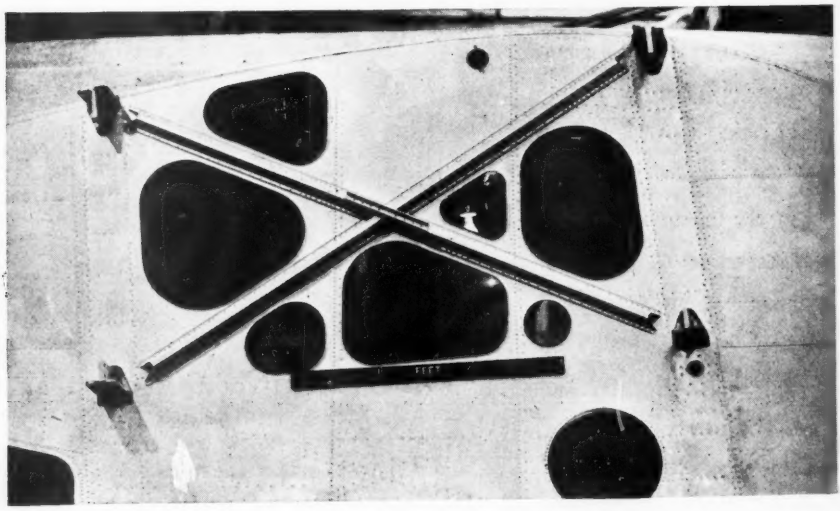

Fig. 15.

blown back in line with the exhaust pipes and along the fuselage belly.

There was little doubt that where these conditions existed exhaust torching caused the fires.

As a result of these investigations design action was taken to re-position the fuel tank vent outlet, and it was conveniently placed at the top of the fuselage aft of the rear cockpit. A non-return ball valve was also embodied in the vent pipe line. The oil breather was re-designed and re-positioned. The exhaust pipes were extended 9 in. so that the exhaust gases were directed farther away from the flaps and fuselage belly.

A suitable paragraph relating to the fire risk of oil and fuel vents in the vicinity of the exhaust system was inserted in ADM. 583.

Fuel tank filler caps

In the year 1945 five instances of fire in flight occurred in another type of aircraft. The most important factors were:—

(*i*) Each fire appeared to have originated in the neighbourhood of the port or starboard exhaust systems.

(*ii*) In four of the cases the pilot lost control of the aircraft.

In the course of the investigations 26 other cases of fire in the air in this type of aircraft were analysed. Of these, 17 were attributed to the presence of free fuel inside the wing becoming ignited by the exhaust flame.

In connection with loss of control in this aircraft, it was a known characteristic that the wing root could be easily stalled and that, should there be a badly fitting cowling or loose panels in the centre-section area, this stall could occur at fairly high speeds and could be very pronounced. In the event of a section of the wing skin or piece of cowling being burnt away, the resulting wing root stall could easily cause loss of control.

There was little doubt that the fires were due to free fuel in the wing coming into contact with the exhaust flame.

There were five ways in which presence of fuel in the wing of this aircraft could be accounted for:—

(*i*) Mishandling of the fuel cocks, so that if the auxiliary tanks were turned on when the main tanks were almost full over-filling of the main tanks would result, with the possibility of the tanks overflowing or fuel leaking past the filler caps.

(*ii*) Fuel spillage due to carelessness while refuelling.

(*iii*) Leaking fuel tanks.

(*iv*) A ruptured fuel pipe line or loose union, or

(*v*) Leakage past an insecure or faulty filler cap.

Of these possibilities, leakage past an insecure or faulty filler cap proved to be the most likely cause. The type of filler cap used was of plastic material and manufactured by three different firms. All were slightly different in design and none was satisfactory as regards fuel sealing qualities. The plastic locking lugs would not stand up to hard wear, and the design of the cap was such that whether or not the cap was replaced satisfactorily depended largely on the individual responsible for refuelling.

As a result of these investigations recommendations were made and the following remedial action was taken:—

(*i*) A new design AGS.607 improved type of filler cap.

(*ii*) Rearrangement of the oil and fuel vent systems.

(*iii*) Enlarged and flush fitting of the anti-splash cups round the fuel tank filler necks to prevent fuel from getting into the tank bays in the event of careless refuelling.

(*iv*) The issue of special warnings.

FIRES HAVE OCCURRED

Take every precaution when refuelling.

See that—Filler Cap Washers are renewed as soon as they become hardened or worn.

See that—Filler Cap is seating correctly when replacing cap.

See that—You do not spill Petrol over Aircraft when refuelling and remove any spilt petrol from filler cap well immediately.

Read F.T.C.T.I.'s D.104 and D.122.

Fig. 16.

No further fires of this description have occurred (Fig. 16).

CRASH FIRES

An aircraft is a rather fragile structure which contains a complex system of tanks and pipelines filled with highly inflammable liquids. The engine exhausts are hot enough to ignite these fluids in a crash and, in addition, there are many electrical circuits which will provide sparks when broken. Should this happen the combustion is generally so rapid as to be almost an explosion. It is clear that to prevent this the best line of attack is to prevent the starting of a fire, rather than to attempt to put it out once it has started. If, then, a fire does break out at the moment of impact with the ground it is usually difficult to obtain any reliable information about its origin from the examination of the burnt-out wreckage. Thus it came to be taken for granted by many people that such fires were inevitable. This rather fatalistic attitude existed until the problem was seriously tackled by the Accidents Investigation Branch in 1944.

As soon as it was possible to reach some conclusions as to how these fires originated, the research workers were for the first time in a position to consider prevention measures. Some of the requirements were the same as in the fire in the air cases. Others were clearly peculiar to the particular problem. As an example: All large modern aircraft are fitted with extinguisher bottles which should discharge automatically on to those parts of the engine installation which are the most likely to cause fire. The means of bringing about this discharge is the inertia switch, which is a device set to go off at some pre-arranged *g* value (Fig. 17).

One of the first facts that emerged from the methodical examination of the wreckage of a number of similar aircraft types was that in a high percentage of these the switch had not tripped. The reason was not difficult to determine. The position of the inertia switch in an aircraft had not been specified. In many cases, therefore, it was placed in the back of the fuselage. Whereas in the majority of cases the nose portion of the aircraft was subject to a very high *g*, the cushioning effect from the collapse of the structure in front of it resulted in a deceleration at the rear end of less than the 6*g* at which the inertia switch was set. Not

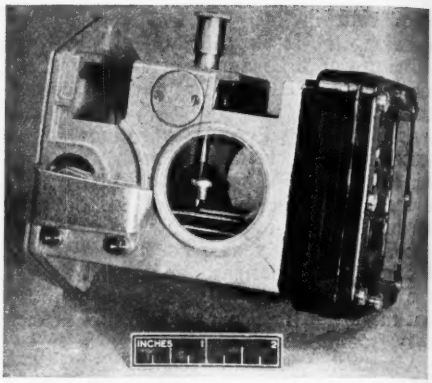

Fig. 17.

until this was realised was the switch placed in the nose or the belly of the aircraft or, in fact, in any position where it would be sensitive to violent impacts other than the normal bumps met with in flight or in taxi-ing.

The inertia switch has served its purpose in many ways but improvements in the system are still exercising the minds of designers. It is believed that the latest system undergoing development is a skin deflection switch.

Another matter to which much attention is being given relates to the advantages or disadvantages of integral tanks, bare metal tanks, crash-proof metal tanks and crash-proof bag tanks. Although it is difficult to obtain both qualitative and quantitative evidence on the subject, because of the extent of destruction usual in serious crashes, it is likely that new design requirements will materialise in due course.

CARBURETTOR ICING

Engine failure because of ice accretion in the carburettor has caused serious accidents. One in particular was the case of an Empire boat which force landed in the Atlantic in 1939. At that time built-in preventive measures against carburettor icing were inadequate in design and largely untried and unproved in actual icing conditions. Arising out of subsequent investigations a re-designed hot and cold air intake system was evolved.

Design requirements now call for a means, adjustable in flight, to give a specified temperature rise over the prevailing outside air temperature and, further, an emergency

means is required for melting any ice which may have formed prior to turning on the heat. Proving tests under icing conditions in flight are now required to show that the de-icing system as installed functions satisfactorily.

Since these design improvements were embodied no serious accident caused by carburettor icing has occurred to a British registered civil aircraft.

COCKPIT DRILL

ALL ENGINES CUTTING OUT SIMULTANEOUSLY DURING FLIGHT

Some years ago five instances of simultaneous engine failures in four-engined aircraft were investigated. The common factor in all the accidents was that all the engines cut without warning shortly after take-off. After the accidents the engines were found to be mechanically sound and each aircraft carried an ample fuel supply.

Investigation showed that it was possible with a low air pressure in the reservoir to start and run the engines with the carburettor fuel cut-off switches in the "cut-off" position. The aircraft could then be taken off, but as the air pressure built up by means of the engine-driven pump, the fuel cut-offs would move to the cut-off position and stop all fuel supply to the engines.

These accidents were primarily due to faulty cockpit drill, but the design of the tumbler type switch for the carburettor cut-offs was such that it could be left in the wrong position (Fig. 18).

Recommendations were made that this type of switch should be changed to the press-button spring return type. The latter has now been embodied and no further accidents of this description have occurred.

FUEL COCK DESIGN

Another accident in which incorrect cockpit drill was associated with poor design occurred in 1938. A twin-engined monoplane took off and when it had reached about 200 ft., both engines failed. The aircraft spun in and all the occupants were killed. Examination of the engines and airframe revealed no defect or failure which would account for the accident. The petrol cock, however, was found to be in the closed position. The operating handle of the cock, which was situated beneath the pilot's seat and operated directly by him, had one long handle and one short end, the latter being provided with a small pointer. As found after the accident, the long end of the handle pointed to the "on" position, *i.e.* the cock was turned off.

This type of accident illustrates clearly that careless design in a small and vital control can lead to confusion and incorrect operation by the pilot.

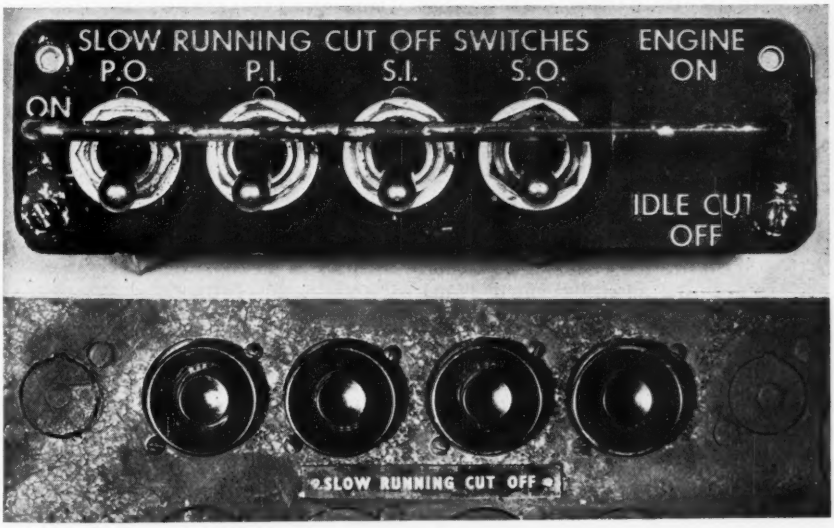

Fig. 18.

Fig. 19.

Locked controls

There are many recorded cases of aircraft being taken off with a locked control. An example was the case of a twin-engined aircraft which took off and on becoming airborne gradually turned about its longitudinal axis until it slipped into the ground. It was then completely destroyed by fire. Examination of the wreckage showed the aileron locking pin still in its locked position in the rod between the control wheel sprocket chain and its underfloor attachment, although the control column casing had been entirely burnt away (Fig. 19). Accidents of this kind were remedied by the introduction of nuisance bars or other foolproof devices.

External locks have also given trouble, particularly those used for the elevators. Various systems are now used, every one of which is looked upon as a normal design requirement.

Pilot's instrument panel

In 1940 and 1941 there was an epidemic of accidents during intensive night flying training. Many of these happened almost immediately after take-off and showed similar characteristics. Reports by the A.I.B. stressed the importance of the careful training of pilots in the quick reading and interpretation of instruments, particularly at the moment of change-over from visual to instrument flying. It seemed likely that as a pilot changed over to his instruments at the time of take-off, or on entering cloud, the memory of a set of visual and other sensory impressions conflicted for a short time with the information which his instruments gave him. Moreover, if the weather happened to be turbulent his task was made more difficult because of the confusion by vibration of the new visual impressions. There was a tendency, therefore, to ignore the instruments as long as possible and, in fact, to rely too long upon aerodrome lighting.

A valuable contribution to this subject was made by Professor Collar and gave rise to some special flying experiments. In these tests, one pilot flew the aircraft with the other under the hood while various manœuvres were carried out. The results confirmed the preconceived opinions, particularly that the act of transference from visual flying to instruments flying could be a potential source of danger, even to a competent pilot. Attention had previously been drawn to this aspect of night flying accidents, but the seriousness of the situation had a marked effect on instrument design and cockpit lighting. One of the chief design features in modern aircraft which was introduced by this particular series of accidents and their investigation was the pilot's instrument flying panel (Fig. 20). Today this is a standard part of the equipment in the crew compartment of every British and foreign aircraft.

CARBON MONOXIDE POISONING

In the early days of the war there were some strange and unexplained cases of aircraft having been seen to dive into the

ground, clearly out of control and often from no particularly great height. The cause of these accidents was difficult to find, although carbon monoxide poisoning was even then being seriously considered.

Complaints were made by pilots of a certain type of single-seater fighter of the smell of exhaust fumes in the cockpit. To quote from a report—" On reaching a height of 4,000 ft. he closed the cockpit cover noticing nothing abnormal. He then engaged in a practice combat during which he partially blacked out in a sharp turn. He remembered nothing more until he came out at 4,000 ft. with the aircraft out of control. He was too weak to read the instruments or open the cockpit cover and passed out again, coming to at 1,500 ft. He then managed to open the cockpit cover and was guided home by his Number 2, remembering nothing after his wheels touched the ground until he was lifted from his aircraft. The Medical Officer tested the pilot's blood and found he had been poisoned by *CO* to such an extent as to endanger his life."

The cause was found to be a faulty connection in the engine sump breather pipe. The pipe consisted of several sections made of metal or fibre and some of the connections were so loose that oil was dripping from them. The R.A.E. reported that exhaust gas and smoke fumes contamination in the cockpit was due to a blow-by of the products of combustion into the engine sump and leakage into the cockpit from these faulty connections.

There were other aircraft affected, although in different ways. In one case the exhaust fumes leaked into the cockpit by means of the step hole in the side of the fuselage and, even when that had been sealed up, through the tail wheel hole. In that case a cure was effected by lengthening the engine exhaust stubs to the extent of about four inches. In another aircraft which had given no trouble with the original engine, *CO* manifested itself almost immediately after a different kind of engine had been installed in which the exhaust pipe ran down the undercarriage leg. Tests showed that the

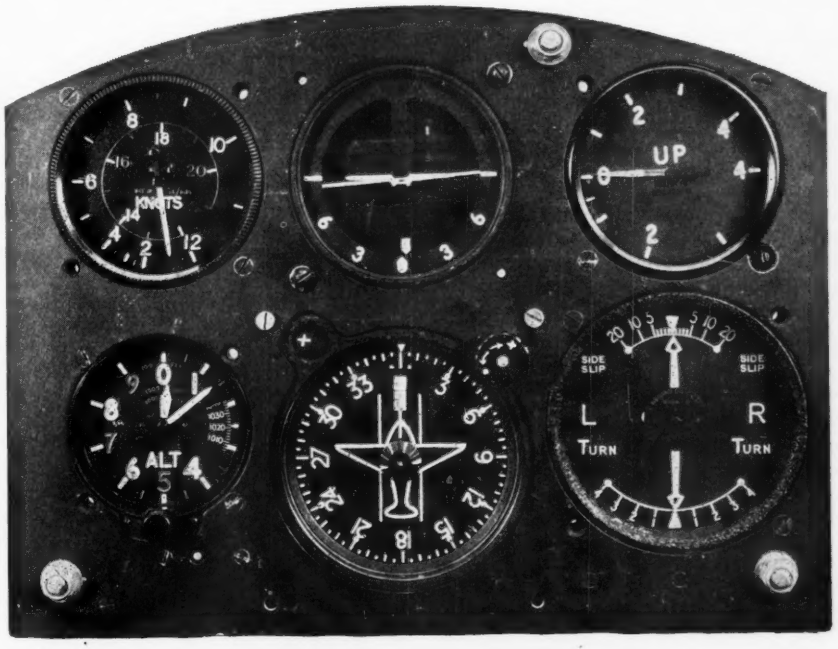

Fig. 20.

fumes were entering through the wing flap orifices and a cure was immediately effected by lengthening the exhaust pipe.

Tests with the mines safety appliance for detecting gas quickly put an end to this kind of trouble so far as it concerned aircraft designed and built in the United Kingdom, and as this appliance was difficult to obtain, the R.A.E. *CO* indicator was brought into general use. Moreover, percentage checks were made of all aircraft coming off the production line, and a *CO* test has, in fact, been made ever since on every prototype aircraft. Since 1943 there has been no record in the Accidents Investigation Branch of any accident from this cause.

HYDRAULIC FLUID

There has always been much argument about the merits of certain proprietary brands of hydraulic fluid. Certain well-known products have suffered from the danger of the toxicity of fumes and, in a series of wartime accidents, it was found that leakage of the hydraulic fluid had invariably occurred. Seepage from jacks, and so on, although undesirable, is not necessarily dangerous, but leakage of the fluid into the cockpit in the form of a high pressure spray can be extremely dangerous. The most common source was found to be failure of the brake hydraulic gauge. Other cases were reported of spray discharge from the pressure pipe of the thermal relief valve. The result of these accidents was the re-design and strengthening of pipe lines and fittings, and for several years there is no record of the same kind of trouble in the systems that are now generally used.

SAFETY BELTS

Long before the beginning of the war the breaking of safety belts or harness had many times resulted in severe facial injury or death. In the early days of hostilities special attention was focused on this problem and recommendations by the A.I.B. initiated research at the R.A.E. Even though improvements were certain in the light of modern requirements, in respect of both civil and Service types, it seems doubtful if the question of breaking strengths of belts and their anchorages would have received so much attention if the initial urge had not come from the results of accident investigations—an urge in which the medical profession in the United States of America, as well as in the United Kingdom, played an important part. The question of the safety advantages or otherwise of backward-facing seats for passengers is still receiving much attention.

CONCLUDING REMARKS

In selecting these cases from the hundreds of records that are available, an attempt has been made to keep to the "technical," as opposed to the "pilot error," only aspect. This has not been easy, as the following example will show. Shortly after a certain new type had been introduced into the R.A.F. its many admirable qualities were marred by an epidemic of undercarriage instead of flap retraction accidents. During night flying the number of cases quickly became alarming. But the cause was not difficult to find. The two levers were the same shape and size, were placed side by side on the pedestal and moved in the same sense. Now who really was to blame? Perhaps there was some justification for the red endorsements in the pilots' log books for, after all, every one of these accidents seemed at first to be the direct result of bad cockpit drill. But when pilots of proved ability, including several chief flying instructors, themselves made the same mistake, it became impossible to avoid the conclusion that a great measure of the responsibility lay with the designers.

If fires and structural failures have been stressed it is because of their importance and because the lessons in those respects have been well and truly learned and have had so much influence upon aircraft and engine design.

It has been said that the finding of the cause of an accident may result in the saving of many lives. This is probably true—in the A.I.B. we believe it is true—but that saving of lives can only be achieved if everybody concerned with the safety of flying, and particularly the designer and manufacturer, will make good use of the information we give them.

Finally, I wish to express my thanks to the Ministry of Civil Aviation, the Air Ministry and the Ministry of Supply for permission to give this lecture.

DISCUSSION

Dr. H. Roxbee Cox (President): There were two kinds of accident which the Lecturer had not referred to, the information gained from the investigation of which had had a profound effect upon aircraft design.

First, there was "flutter," which was recognised in the 'twenties. Some famous biplanes were the victims of a number of inexplicable accidents, and it took a long time to deduce the truth from the evidence. A major problem confronted the investigators, but in time it was understood. The information collected from that series of accidents not only materially modified aircraft design but was the forerunner of the establishment of a new branch of aerodynamic and structural science, now called "aeroelasticity."

The second class of accident was "buffeting"; a classic instance was the failure in the air of a Junkers monoplane at Meopham in 1930. The evidence was conflicting and difficult to understand, and he did not think a complete explanation of that particular accident had ever been given, but this accident led to the discovery of yet another cause of structural failure in the air and the development of a further change in aircraft design. The relation between the position of the tail and the rest of the aircraft in fact was called into question for the first time for many years.

Prof. A. R. Collar (University of Bristol, *Fellow*): He believed that they had been especially fortunate in Great Britain in the group of men Air Commodore Vernon Brown had gathered round him to form the Accidents Investigation Branch.

Not only did he think an accident investigation organisation was desirable, he thought a few accidents were desirable, in a long-term sense. In the short-term sense, accidents were always unfortunate and most regrettable, especially if fatalities were involved. But he believed that, taking the long view, the ultimate good which could accrue from an accident—provided it was properly investigated—far outweighed the immediate disadvantages. An accident could provide data for a quantitative survey of safety margins, could reveal local weaknesses, and so forth; but perhaps most important it could provide the stimulus for research, and so pave the way for improvements in design.

The episode on the question of the tensioning of control circuit cables had occurred at the time when his group at the Royal Aircraft Establishment was responsible for advising the Ministry on stiffness matters, including control circuit stiffnesses. They had laid down appropriate stiffnesses, but had not at the time realised how necessary it was to prescribe a certain standard of pre-tensioning. The incidents showed clearly that lack of pre-tensioning could produce a serious loss of effective stiffness, and investigation showed that an increase in tension not only produced elastic extension, but also took up the sag between supports: with the result that the constant elastic flexibility was increased by a "catenary flexibility" which was inversely proportional to the cube of the pre-tension. For the particular aircraft concerned, the investigation suggested that a pre-tension of about 50-60 lb. would reduce the catenary flexibility to insignificant proportions. As a preliminary to recommending this figure, they enlisted the aid of the Accidents Investigation Branch to organise a survey of the pre-tensions being used in service conditions. Three hundred aircraft were examined, and pre-tensions varying between 180 lb. and 3 lb. were measured. The serious implications of the latter figures were obvious in view of the cube law just mentioned.

In this connection he had always felt that he would welcome a public opportunity of paying tribute to the work of two members of the staff of the R.A.E., R. Moffatt, who devised and made up the prototype of the now well-known R.A.E. tensionmeter, very much in its final form, within 24 hours of their realisation that some such instrument was required; and F. Alexander, who produced from the prototype the various drawings required for the different sites and marks, found a firm to undertake the making, organised the contract, and had production models flowing into service in a remarkably short space of time.

He had indicated how closely connected he had been with the investigation of this series of accidents; yet he did not know what effect the measures taken had had upon the accident rate until he read in the lecture that the rate had decreased from one in 16,000 to one in 82,000 hours. He would

suggest, therefore, that when the rate of occurrence of a particular type of accident was reduced to such proportions that the Investigations Branch felt that that particular casebook could be closed, a brief report should be made and issued of the whole story—accident history, conclusions of inquiry, curative measures and results. Such a report would be extremely valuable.

He also had noted the absence of reference to flutter accidents. Was the number of failures due to flutter relatively small in the totality of accidents? The first flutter accident of which they had a recorded investigation occurred in 1916; the practical investigation was made by Lanchester and the theoretical study by Bairstow and Fage. The whole of the theory of flutter—nowadays a complicated and extensive subject—had been prompted by accidents and accident investigation; and a most important phase of their knowledge of fluid flow therefore was derived from those accidents.

If they looked at some of the fields in which research had materially assisted aeronautical progress they might remark that, while theories of performance had not been particularly associated with accidents, studies of stability and control had derived almost exclusively from accidents, or at least incidents. In the structural field, perhaps half their knowledge had derived, directly or indirectly, from major or minor failures. Professor Pugsley, who was unable to attend the lecture, had suggested an illustration of this. Some years ago there was a series of failures in a screwed joint in a wing spar, due to fatigue. From the investigation of those failures and of similar subsequent troubles there grew up first a theory of fatigue of structures, then a theory of repeated loads, and finally a philosophy of the life of aircraft structures under fatigue and repeated loads. That philosophy was now beginning to have a real effect on aircraft design, both here and in America; it was a philosophy which had its beginning in those early accidents, and provided another example of the good which might ultimately accrue from an unfortunate beginning.

Marcus Langley (Tiltman Langley Laboratories, *Fellow*): The Chief Designer of an aircraft firm in his drive for greater safety, always had a Stress Office under a competent senior stressman investigating the safety of structures. He also had his Aerodynamics Department, concerned with problems of safety as affected by stability and control. This should be extended to more practical aspects. They should consider not only stress and aerodynamics but should embody them in a bigger conception, which might be called a Safety Office. Certain members of the staff would be highly experienced in repair and maintenance, and perhaps even in accident investigation. It would be the duty of those people to inspect every drawing in the light of fire, crash and other similar risks with the same degree of thoroughness which the existing stressman showed in studying the drawings from a strength point of view.

Information as to the causes of all accidents and defects and the remedial measures to be taken should be circulated free of charge to every stressman, designer and draughtsman in the country.

W. Tye (Air Registration Board, *Fellow*): Only that evening had he fully realised the profound effect which the Accidents Investigation Branch had had on the whole of the present code of requirements.

He doubted whether this state of affairs would continue to exist and he looked to the time when accidents became so infrequent that the lessons to be learned would be so rare as to become unreliable for the purpose of obtaining information on which to base future work. As design developed it was clear that requirements would need to keep pace with that development, and they must, therefore, have some basis for future requirements, and it might well be that it would have to be other than that provided by accident investigation.

They would have to look towards the "near" accident, many of which were the ordinary defects. There was in being machinery for the collection of defect reports and, to some extent, this had guided them in the past in preparing requirements, but he did not consider the machinery really sufficient. In addition to the ordinary defect there were innumerable occasions when accidents which were only just avoided were not related strictly to any defect but nevertheless had a bearing on design. The more successful the Lecturer was in teaching them how to design aeroplanes to avoid accidents, the less they would be able to look to him in the future for this information and, therefore, he or somebody would need to provide them with information regarding the

"near accident," including the straightforward defect.

Stalling was one of the principal causes of fatal accidents during the war, and if this could be removed a major danger would be eliminated. The Lecturer had referred indirectly to stalling in his reference to leading edge slots, and in fact appeared to suggest that the structural menace from the leading edge slots was greater than the stall which they were meant to prevent. That implication might not have been intended, but did the Lecturer think stalling was still a big problem? He appreciated the difficulties involved in providing a hazard-free stall, but felt that if the position were the same as during the war, another effort by designers would be well worth while.

Accident investigation could provide a guide to other matters besides design, in particular the operational side. Lessons could be taught to the pilot, maintenance engineer, and the operator. There was already a certain amount of information springing from accident investigation and finding its way to the people who flew aeroplanes. In one magazine (he thought an R.A.F. publication) people were being instructed on the misdeeds of others and the way pointed to safer flying. There were posters, too, at R.A.F. stations. Such propaganda was extremely useful, because for lessons to be learned they had to be repeated time and time again. On the civil side there had not been much recourse to such propaganda. It was always assumed that the Licensed Aircraft Engineer and civil pilot did not need further advice on how to fly or maintain their aeroplanes, but some well-planned propaganda might prove beneficial.

As the work of the Lecturer was bearing such useful fruit on the design side, would there not be equally good results if the information were spread in other directions?

Group Captain F. Wilkins (Ministry of Civil Aviation): After twenty years in the Accidents Branch he had gone to Canada in December 1941 to form the Accidents Investigation Branch there and returned to the United Kingdom last year.

There had been a batch of structural failures among some light twin aircraft in Canada used for Service training. This was hardly a design fault, as the aircraft had actually been designed for private taxi work. He was able to find complete evidence about the failure, which was associated with the nose ribs. The number of ribs was doubled, and a cure was effected.

There had been a number of structural defects in a low-wing light monoplane. There were a series of crashes and tests revealed the fact that the centre section was nearly 40 per cent. below strength. A medium bomber in Canada had suffered three accidents at night in rapid succession on take-off. It was discovered that the port magneto switch was being accidentally knocked off by the pilot when he used the undercarriage lever. These were very close together, and the thickly-gloved hand of the pilot—gloves had to be worn in Canadian winter conditions—was responsible.

Cable tensioning presented difficulties in an extreme climate such as Canada; it could be done without difficulty in the heated hangar, but the work was nullified by contact with the outside air; temperatures at 40 degrees below zero F. soon slackened the cables. There was considerable trouble of this nature until the Winter Experimental Station put things right.

Designers should keep an alert eye on the fire menace, in the interests of passenger safety. An emergency exit which did not jam was a major requirement.

D. J. Lyons (Royal Aircraft Establishment, *Assoc. Fellow*): Air Commodore Brown had not mentioned the need or otherwise for the aircraft to be so designed that full pilot's loads on the cockpit controls should not cause breakage of any part of the aircraft structure.

It was a well established feature of military aircraft design requirements that the loads on the cockpit controls should either be sufficiently high to prevent, or to dissuade, the pilot from applying dangerous loads to the aircraft structure, or, alternatively, there should be some other form of preventive action, such as the "blackout" due to increase of normal g, occurring with sufficient margin away from the dangerous load condition. Those rules were necessary because the military pilot was often in a situation where he could not pay sufficient attention to the degree to which he was stressing the aircraft, and also because his aircraft was often required to manœuvre in such a way that the stresses were a considerable proportion of the breaking stresses.

What was the position with civil aircraft?

The stresses during the required manœuvring were only a small percentage of the structural design maximum stresses usually set by the "gust" cases, and the pilot was required by passenger comfort considerations to fly his aircraft in a gentle manner. Should they allow for occasional rough handling, say due to collision risk, when they could not rely perhaps on the pilot limiting the aircraft stresses sufficiently, and make the control loads high so as to be safe during such infrequent occurrences, with the resulting detriment to normal flying? He thought it would be wrong to sacrifice efficient and easy handling of the aircraft in order to cope with those infrequent cases, but in what light did the Accidents Investigation Branch see it?

Should the automatic pilot on any civil aircraft be so limited that it could not break the aircraft even if it applied full force in any direction, or was the fact that the pilot was able to overcome the auto-pilot a sufficient safeguard? Provided the civil pilot was required by statute to be strapped in like a military pilot, he thought the latter alternative would be acceptable and preferable, but again, as the matter was likely to be controversial, what did the Accidents Branch think?

B. Cornthwaite (British South American Airways, *Associate*): He thought the Lecturer had not made it quite clear that the Accidents Investigation Branch was officially interested only in those accidents which came within the definition of a "reportable" accident. There were many accidents which fell just outside those limits, but which might conceivably produce useful information for the designer.

In civil airline operation, investigation of that type of accident was the responsibility of the operators and at all three Corporations there were departments to undertake that work. The A.I.B. investigation was made with the ultimate object of finding the cause of the accident, but as a rule no suggestions or recommendations were made regarding remedial action. The operators' investigating team wanted answers to such questions as:—"Were the passengers strapped in?" "Did the seat fittings hold?" "Did the passengers get out of the emergency exits?" "Were those convenient and sufficient in size and number."

That work might be regarded as complementary to the excellent work already being done by the A.I.B.

Another function of the operators' investigating team was the investigation of defects which, if not rectified, could easily be either a primary or a contributory factor in a serious accident, such as an unreliable windscreen wiper, inaccurate instrument readings, failure of the captain's seat adjustment, cases of static discharge, and so forth.

Designers, if possible, should brief one of their technical representatives to follow up all accidents with the operators and with the A.I.B., so that information gained could be transmitted directly to the design office. By that means a designer could effect improvement immediately and not have to wait until the improvement formed the subject of an Air Registration Board design requirement. If this could be arranged the next logical step would be an interchange of information between design offices.

J. G. M. Pardoe (Air Registration Board, *Assoc. Fellow*): There was a very real need for the investigation of the results of crashes. Civil design requirements contained several —what might be termed—"crashworthiness" provisions. To name a few:—Safety belt and seat strength, emergency exits and crash fire precaution systems were called for. Those requirements, for want of a better foundation, had had to be based on theory developed from the evidence of war-time military aircraft and American light aircraft research. Besides its present invaluable work of setting forth the events leading to an accident and a laconic statement of the scale of human casualties involved, it was most desirable that accident investigation should provide every available scrap of evidence that might be used to reduce the casualties in any accidents that occurred in future. Information was required not only as to how the safety equipment provided worked or did not, but also as to how injuries were received or why they were not, what the occupants did or attempted to do and what they were capable of doing, not only if they escaped (if that were the case) but also how they were able, or unable to escape; also every possible scrap of information influencing crash fires was required. It must be conceded that such investigation might require small additions to staff and that there was a manpower shortage; but so there was in the war, when the powers-that-be had the wisdom to authorise a really promising investigation into the crash fire problem. Surely in a safety matter at least as much should be done for

airline accidents as was considered expedient for bombers in war-time.

The A.I.B. was most open and helpful when approached on any matter. What was lacking was some routine dissemination of accident information without the delay of waiting for a final report which might or might not be published and without having to make an approach on each occasion; also whatever facts were known of notified but uninvestigated accidents should be made available. That information might well be given in periodical issues of a regular series. A factual summary of the information on each accident could be given, particularly as relating to the behaviour of the aircraft and its equipment, and the physical circumstances of the damage. There would be no need to include the identification of the particular aircraft or operator, any names of persons, or even any opinions. Such a series should be received and considered in every aircraft design office. It would, he felt, serve a useful purpose in keeping designers informed of what were the dangers in flying. It would be a useful complement to the series which the Lecturer mentioned the S.B.A.C. was proposing to organise of examples of detail design which had given trouble.

H. S. Crabtree (British Overseas Airways Corporation, *Assoc. Fellow*), *contributed*: Air Commodore Vernon Brown almost skated over "human error" as a primary cause in aircraft accidents. From the civil airline operator's point of view, the differentiation of the prime cause as between human error and mechanical or other failure, was really of little consequence. The chief necessity of a civil operator, once an accident had occurred, was to establish beyond doubt in the shortest possible time the causes, or probable causes. The Aircraft Industry and the civil operator up to the present time had been more interested in the direct causes. As stated at the Lecture, direct mechanical causes of accidents were now only responsible for ten per cent.

It was interesting, therefore, to turn to the American domestic airline accident statistics as published by the Civil Aeronautics Administration, where, during the past 15 to 20 years, certain trends were occurring which the civil operator was inclined to think were not appreciated by the designers and such agencies for obtaining new aircraft as the Ministry of Supply. Taking the American statistics for the prime causes of accidents, and expressing them as percentages of total accidents caused in one year, the following table of prime causes was obtained:—

ACCIDENTS TO AMERICAN DOMESTIC AIRLINES: CAUSES OF ACCIDENTS

All figures expressed as percentages of total number of accidents during the year

Year	Personnel Errors	Power Plant Failures	Structural Failure	Weather	Others
1930	24	20	7	30	19
1931	21	19	17	24	19
1932	14	22	18	29	17
1933	19	24	15	23	19
1934	32	19	17	16	16
1935	29	22	17	17	15
1936	41	10	23	7	19
1937	22	2	23	24	29
1938	39	12	18	19	12
1939	42	7	6	9	36
1940	53	6	18	12	13
1941	56	2	17	9	16
1942	41	6	11	12	30
1943	35	12	12	20	21
1944	49	—	7	22	22
1945					

It was possible to break these figures down further, especially so far as the percentages of accidents caused by personnel errors were concerned, when the following figures were obtained:—

Year	Personnel errors of all types %	Pilots errors %	Personnel other than pilots %	Average Cruising Speed
1930	23.75	21.19	2.56	Not known
1931	20.77	17.82	2.59	Not known
1932	13.75	12.59	1.16	104
1933	18.55	17.55	1.00	116
1934	32.11	24.08	8.03	127
1935	29.49	24.14	5.35	142
1936	41.15	31.77	9.38	149
1937	21.90	17.50	4.40	153
1938	38.64	33.79	4.85	153
1939	42.27	36.21	6.06	153
1940	53.11	46.91	6.20	155
1941	55.76	46.21	9.55	159
1942	40.81	30.32	10.45	159
1943	34.58	25.42	9.17	160
1944	49.47	44.47	5.00	162
1945				

Would Air Commodore Vernon Brown express his opinion, therefore, on the following points:—

Did his experience line up with those American figures; in other words, was there a tendency for accidents resulting primarily from human errors to be increasing in proportion to those due to mechanical or other reasons?

Did he consider that those human errors had any relation to the average cruising speeds employed? He had inserted the

average cruising speeds obtained on the American domestic airlines in the second series of figures, and it was interesting that the increase in percentage of accidents due to pilot errors followed fairly closely the increase in average cruising speeds.

Could Air Commodore Vernon Brown make any suggestions of the causes of those increasing pilot errors? Did he think, for example, that the pilot's brain was overtaxed by a multiplicity of gadgets and instruments, or that the characteristics of modern aircraft required physical reactions of such a speed that they were now beyond the capabilities of the brain and body to accomplish? It was obvious to an aircraft operator that the more "safety devices" applied in modern aircraft the more equipment there was to maintain and overhaul, and the less likelihood was there of obtaining high utilisation hours for aircraft and hence, increasing economy.

Economically, therefore, the civil aircraft operator was clamouring for simplification and less "gadgetry." Was it possible that Air Commodore Vernon Brown's experience would indicate that such a policy might of itself reduce accidents due to human error?

He was convinced that a great number of accidents in civil air transport had been avoided during the past years because of action taken by the airlines' engineers. As a result, those with many years' experience were aware of requirements in civil aircraft that they considered essential if new aircraft were to give safety of flight, ease and increasing economy of operation. It was somewhat tragic, therefore, after all these years, that they were placed in the position of having to operate aircraft which had features embodied for which there was ample previous experience to justify the demand that such features should have been avoided in new aircraft. He could quote one simple example.

In Imperial Airways it became the agreed policy of the engineering department, based on its day-to-day engineering and operational experience, that they should not operate aircraft where the fuel was virtually mixed up with the passengers, freight and crew, by being located in part of the fuselage. Accumulated experience indicated a great number of possible risks from such an arrangement. Yet, after such a decision had been made, a new civil aircraft was placed on service with fuel tanks in the fuselage. Ample precautions had been taken by the manufacturer, but nevertheless this was an instance of a principle which could be justified by long detailed experience being over-ruled for political, design expediency and other considerations.

It was tragic that even today, with the possibility of less dangerous fuels being used in the aircraft through the adoption of jet engines, designers were still going back to placing fuel tanks in the fuselage on the plea that this was the only place where they could locate all the fuel required.

He agreed with Air Commodore Vernon Brown that far more attention must be paid by the manufacturers to building in to their new aircraft the lessons learned from accident investigations; almost as great an improvement could be made in civil aircraft if the designers would also absorb all the experience gained by operators in the practical day-to-day operation of existing and past civil aircraft.

F. Grinsted (Royal Aircraft Establishment, *Assoc. Fellow*), *contributed*: A relation existed between structural failure, airworthiness, and design efficiency. The structural design requirements for aircraft were based on loading conditions judged to occur rarely. Greater loads were possible, although they would occur infrequently; but to cater for them would demand so high a strength and structure weight that the performance of the aircraft would be poor. It was inevitable therefore that there would be some structural failures, particularly to aircraft types of which large numbers were in service. Such failures, which so far had been few and sometimes caused by rash pilotage, must be distinguished from the many accidents caused by design faults that reduced the standard of airworthiness to less than the prescribed level.

Several years' investigation of structural failures and defects taught him how many and various the design faults could be, from bad detailed design to inability to predict accurately air load distributions or flying characteristics. The inability was no reflection upon the designer; it resulted from aeronautical theory not keeping pace with practice which progressed on judgment and by trial and error—with the occasional unforeseen accident. It was in such accidents that painstaking detailed investigations could make valuable contributions to research in aerodynamics, structures, and metallurgy.

N. J. Hancock (Ministry of Supply, *Assoc. Fellow*), *contributed*: Those who had had contact with the Accidents Investigation Branch staff were invariably impressed by their abundance of commonsense and their versatility. How were such staff selected? The information would be of value to all others interested in the recruitment of engineering staffs.

In his Scrap Book for 1921 he had a cutting from a popular American Magazine which gave a drawing and description of a Control Cable Tension Meter almost identical to the present-day unit. Surely, Farnborough should not be credited with its invention, 20 years later?

W. S. Hollyhock (*Assoc. Fellow*), *contributed*: The Lecturer dealt at some length with fire hazard. This was only right and proper, although the "Fires" branches did appear to designers sometimes to overstress that particular aspect of safety precautions. This was naturally more noticeable with single-seat aircraft where weight and space were of paramount importance and the inclusion of odd bits of electrical equipment, which it was hoped would never be used, constituted a problem.

He wished that the Lecturer had told more of the methods of detailed examination which led up to a solution of the problem of why an accident had occurred.

Air Commodore Brown quoted a report which said: "All five accidents investigated by this Branch appear to have a common feature in the instability failure in the main-plane front spar compression boom . . . ."

The hours of work and the analytical concentration that probably went into the investigation before it was possible to make such a report could be imagined, and the methods of approach to the problem should be illuminating and instructive to those engaged on the design side.

J. A. C. Manson (Fairey Aviation Company Ltd., *Fellow*), *contributed*: It was frequently suggested that maintenance for maintenance sake caused more troubles and defects than downright lack of maintenance; the suggestion obviously being to leave well alone.

What were the Lecturer's views on this problem?

The obvious implication in relation to aircraft design was that aircraft should be designed not solely for ease of maintenance, but, more important still, for the absence of need of maintenance.

J. B. B. Owen (Royal Naval Scientific Service, *Assoc. Fellow*), *contributed*: In investigating aircraft accidents involving structural failure, the designer was never satisfied unless he was able to calculate that sufficient load could come on the part which had broken to cause it to fail in the way it did in the accident. Indeed, the accident was not properly explained and little technical knowledge was gained unless such calculations were made. In the course of studying accidents, while he was at the Royal Aircraft Establishment and working in co-operation with the Accidents Investigation Branch, he was struck with the number of times in which great difficulty was experienced in accounting for enough load to break the parts which had failed. Sometimes even after strength and wind tunnel tests, no practicable load system could be found large enough to account for the failures arising in practice. This was, on occasions, the only clue available to the probable presence of dynamic effects which had previously not been suspected.

In studying structural failures instead of the usual factors of 2, 1.5 or 1.3, which were usually used, a factor of unity was worked with, and calculations based on factors of 1.5 and 2 frequently had no meaning. If, therefore, a real view were to be taken of ultimate strength design the associated factor should be unity.

He was glad that Air Commodore Vernon Brown emphasised that structural failure did not necessarily mean that a structural error had been made. Structural failures had often revealed defects in detailed design, the presence of an elastic instability which had previously been neglected and so on, but the real value of examining a structural failure lay in the key it afforded to the cause of an accident and the action to be taken to prevent further accidents. Air Commodore Vernon Brown had laboured untiringly for many years with this object in view.

J. Smith (*Associate*), *contributed*: In connection with crash fires the author had remarked "there are many electrical circuits which will provide sparks when broken. Should this happen the combustion is generally so rapid as to be almost an explosion."

It was fundamental that a fire could only be produced when an inflammable material came into contact with a source of ignition.

Bearing this in mind it seemed odd that so little had been done to isolate automatically the inflammable fluids from the sources of ignition in a crash.

It was useless to expect the pilot or the flight engineer to turn off all fuel cocks prior to hitting the ground. In most cases the pilot had no indication that a crash was imminent and even where the pilot had some realisation that the circumstances were critical, he was not only fully employed with other urgent matters but might be relying on full power to get him out of a difficult situation. Even with fuel cocks all off, the fuel was not isolated as, even where crashproof tanks were installed, they did not always all have cocks and those that did invariably had their cocks situated some distance away, so that the rupture of the pipeline between the tank and the cock prevented isolation.

Hydraulic fluid under high pressure was another potential source of fire in a crash and this could not be isolated.

The modern public transport aircraft contained, literally, miles of wire for the electrical system, all of which was alive at the moment of impact in a crash. The chances of a short circuit spark were legion.

Surely the operation of the inertia switch should be to render automatically "dead" all electrical circuits.

It would appear that those aspects of crashworthiness had received no attention from design staffs and, until they did, fare-paying passengers would perish unnecessarily in crashes entirely because of burns.

THE REPLY TO THE DISCUSSION

He understood that the Society of British Aircraft Constructors had agreed to circulate information to its members. He thought that the S.B.A.C. had access to such details as they required from the technical aspect. He was inclined to disagree that the Accidents Investigation Branch did not always bring the manufacturer and designer, as well as the operator, in on the ground floor. Little was withheld from the Industry. The Air Registration Board also had access to the available data. It was virtually impossible to write in detail on every scrap of information obtained, and even if it were possible it would be unwise to distribute it on the offchance that it might prove useful. Information was seldom refused. He thought the S.B.A.C. was the instrument through which those details should be passed to the trade.

"Incident" reporting was a difficult problem. It was not binding upon anyone to report an incident, but only an accident which fell within the definition contained in the Regulations. Nevertheless many incidents and minor accidents did come in. An enormous staff would be required to sift them if it ever became mandatory. It was up to the operating companies and the ground engineers to give the information to the Air Registration Board, and in this way enable it to be passed around. Any assistance or advice requested was readily given by the A.I.B., provided that the staff was available, but the Branch did not hear of all incidents. He certainly would much prefer to hear of a fire which had occurred in flight and had been dealt with satisfactorily, rather than have to look at the debris on the ground, but the Branch had no power to demand a report of such a case.

There were the slow-speed and the high-speed kind of stall. Stalling still constituted a danger, but a device to combat it would probably represent yet another addition to the already large number of gadgets in the pilot's cockpit.

He could not give quick answers to other points raised, such as the use of the automatic pilot and whether a pilot should be able to over-ride it. He emphasised that his paper dealt only with the technical aspect and not with pilot's error.

Professor Collar: All the Accidents Investigation Branch reports on the cable tensioning cases to which reference was made in the Lecture were circulated to the Ministry of Supply, the Royal Aircraft Establishment and the manufacturer of the particular type of aircraft. They happened during the war and gave rise to Service and civil airworthiness requirements.

That there had been very few cases in which the question of flutter had had to be considered during the past few years was probably due to the almost complete elimination of this phenomenon as a result of the work of people like Professor Collar.

Structural failures in the air had certainly increased the knowledge about the strength of aeroplanes generally and the forces to which they might be subjected. But it was likely they still did not know as much as they would like on the subject of fatigue.

Mr. Tye: He thought Mr. Tye misunderstood him about the stall danger. That there was a danger was readily admitted but stalling had never been one of the major causes of accidents. His reference to the use of slats in school aircraft and to the danger of the use of slats in high speed aircraft needed no further explanation. With proper training that danger was not very great and, as a personal expression of opinion, he had always been doubtful whether a special stall warning device would be really worth while, having regard to the already large number of instruments, and the like, in the pilot's cockpit.

He wished he could share Mr. Tye's optimism about accidents becoming so infrequent that the lessons to be learned were likely to be rare. He agreed about the need for accident prevention propaganda. He had always urged that accidents should be talked about and that all the information obtained from an investigation should be available to those who wanted it.

Mr. Lyons: Whereas "comfort considerations" might influence the pilot of a passenger aircraft, he thought Mr. Lyons belittled the common sense and general high standard of flying with which might be associated the good form generally exercised by commercial pilots. He agreed it would be wrong to sacrifice efficient and easy handling of an aircraft in order to allow for the infrequent high stressing kind of accident. He thought the fact that a pilot could overcome the automatic pilot should be considered as a sufficient safeguard.

Mr. Cornthwaite: It was not strictly true that the Accidents Investigation Branch was officially interested only in "notifiable accidents." The Regulations made it permissible to investigate any accident if it seemed desirable to do so, and Mr. Cornthwaite would doubtless recollect several occasions on which this had been done. It was true that an A.I.B. investigation was for the purpose of finding the cause of an accident, but recommendations were often made and, in any case, every accident report issued by the Branch was energetically followed up by the safety department of the Ministry.

It was not always possible to give information as to whether the passengers were strapped in, and so on. If the matter were relevant it was referred to in an A.I.B. report. To give details of the condition in which everything was found would make a report an unnecessarily lengthy document, but because all the details were not there did not mean they were not available if required.

Mr. Pardoe: The research into the causes of crash fires had not ceased. It was, of course, true that the same facilities did not exist in peace-time as in war-time and that their activities had been somewhat curtailed in this respect.

There was a considerable amount of "investigation of the results of crashes." It was done by the safety department of the Ministry of Civil Aviation, often in conjunction with the Air Registration Board and the Ministry of Supply. The operators and the manufacturers were also often in the picture. The dissemination of information about accidents was a difficult problem, but Mr. Pardoe would remember that his terms of reference were to investigate and make a report to the Minister.

Mr. Crabtree: He purposely avoided dealing with the "human error" class of accidents. It would easily make a subject for another lecture. Besides, statistics were not the responsibility of the Accidents Investigation Branch.

Mr. Hancock: Staff for the Accident Investigation Branch was selected, in the case of Inspectors, from commercial pilots with considerable experience of flying and with navigational and other qualifications and, in the case of Investigating Officers, from men who had had engineering experience connected with aeronautics over a number of years, from drawing office to the inspection stage.

The selection was made by a board of Civil Service Commissioners.

Mr. Manson: Aircraft had to be maintained to a schedule which was evolved by the Air Registration Board and the manufacturer as the result of experience. The number of defects which had been brought to light as the result of this system was sufficient justification for its continuation. It was not agreed that faulty maintenance might constitute a case for lack of, or no, maintenance. Records showed, however, that the percentage of accidents due to faulty maintenance was small.

Mr. Smith: He thought Mr. Smith was under a misapprehension. A great deal had been done and it was by no means true to say that "these aspects of crashworthiness had received no attention from design staffs."

One of the A.R.B. Civil Airworthiness Requirements was to the effect that "fire extinguisher systems shall be designed and installed to extinguish fires during flight. In addition, means shall be provided to render them as effective as possible in reducing the hazard of fire following a crash of up to moderate severity."

Much research had been going on on the question of the isolation of fuels and tanks and of the use of inertia switches and other similar devices. Unfortunately, equipment of that kind could not yet be said to be a hundred per cent. perfect and while there was always the weight penalty to be considered, the additional possibility of inadvertent operation must not be forgotten. He would suggest that Mr. Smith should ask the A.R.B. what was the latest position in respect of fire prevention in aircraft.

HIGH LIFT DEVICES AND THEIR USES

by

R. R. DUDDY, B.Sc., A.F.R.Ae.S.

The 778th Lecture to be read before the Royal Aeronautical Society (the second main Society Lecture to be given at a Branch centre) was read under the auspices of the Portsmouth Branch, at the Portsmouth Municipal College, on 21st April 1949, by R. R. Duddy, B.Sc., A.F.R.Ae.S., on "High Lift Devices and their Uses." Sir John Buchanan, President-Elect of the Society, presided over the meeting with Mr. E. C. Green, Chairman of the Portsmouth Branch.

Opening the meeting Mr. Green said that only once before had the Royal Aeronautical Society met outside London and that was at Birmingham in October 1948. Now Portsmouth was honoured, and he extended a warm welcome to Sir John Buchanan, Mr. N. E. Rowe, Vice-President of the Society and Chairman of the Branches Committee, and Mr. D. C. Smith, Secretary of the Branches Committee. He also welcomed contingents from the Isle of Wight and Southampton Branches.

Sir John Buchanan apologised for the unavoidable absence of the President, Dr. H. Roxbee Cox. The Council realised that the main lectures given in London were only available to a limited section of the members of the Society and they were endeavouring to distribute the main lectures over the country.

He had much pleasure in introducing the Lecturer, Mr. R. R. Duddy, Senior Scientific Officer in the Flight Section of the Aerodynamics Department, Royal Aircraft Establishment, who, since 1943, had been in charge of the Flight Group working on take-off and landing problems, with special reference to Naval aircraft.

1. INTRODUCTION

Since the early days of aeronautics an immense amount of work has been done on a large variety of devices for increasing the lifting properties of the basic wing section. As long ago as 1916 the Fairey Aviation Company fitted a trailing edge flap to a wing with the object of increasing lift and later fitted flaps as a standard item on many of their production aircraft. In 1921 a patent was taken out on a split flap by Orville Wright and J. M. Jacobs and in the same year a past president of this Society, Sir Frederick Handley Page, read a paper describing his work on the leading edge slat and trailing edge slotted flap. The development of trailing edge flaps proceeded with the object of producing larger and larger lift increments. Eighteen years later, in 1939, the results were published of tests on a double Fowler flap developed at the Royal Aircraft Establishment, which gave a maximum lift coefficient of 3.5 and the addition of a leading edge slat increased this to nearly 4.5. These values probably still represent the highest lift coefficients reached without use of additional power.

At this stage in the development of high lift devices, it is probably true to say that larger lift coefficients could be produced in the wind tunnel than could be used on aircraft in flight, because of the difficulties of maintaining trim and stability. In recent years work has been directed mainly towards overcoming these aerodynamic problems in the application of high lift devices. At the same time some progress has been made towards simplifying the structural and mechanical problems associated with the operation of high lift flaps.

The object of this paper is to review the existing information on the aerodynamic characteristics of practical high lift devices and to examine the problems associated with the application of such devices. The uses of high lift coefficients will be examined to determine the advantages to be gained and to determine how these are affected by the characteristics of the aircraft and airworthiness requirements. Finally, the effectiveness of high lift devices on swept-back wings will be considered briefly.

The increase in the structure weight of the aircraft involved by the various methods of

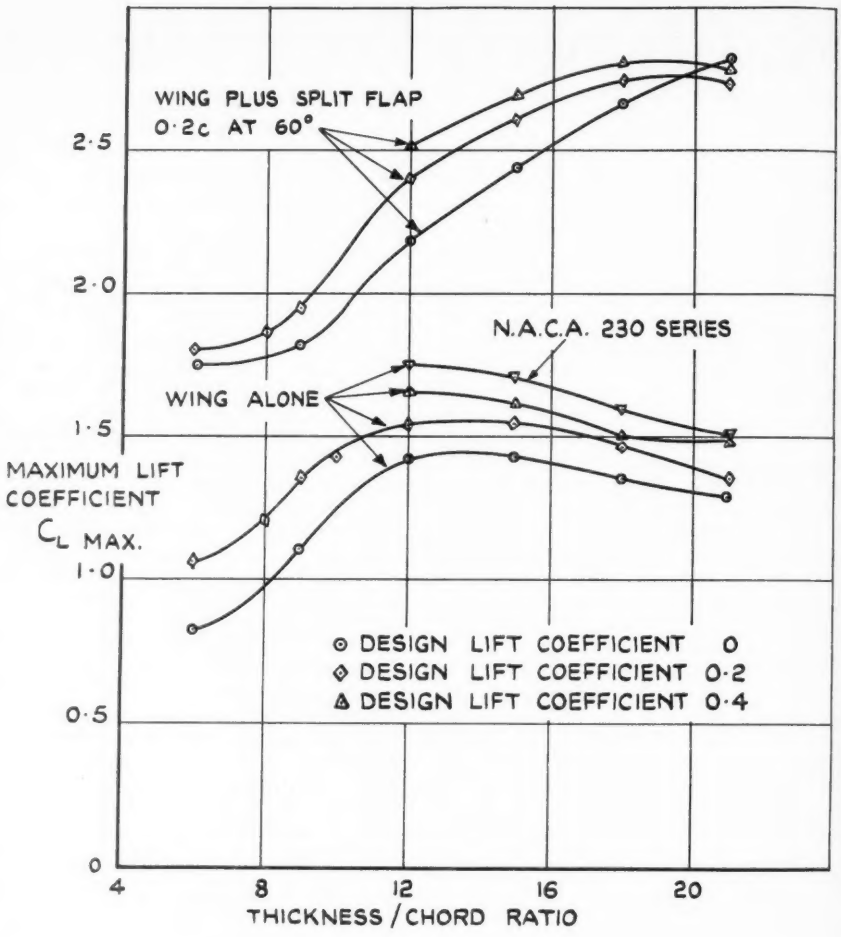

Fig. 1.
Variation of maximum lift coefficient with aerofoil thickness/chord ratio two-dimensional tests on N.A.C.A. 64 Section at $R = 6 \times 10^6$.

obtaining high lift coefficients is clearly of considerable importance, but this is unfortunately outside the scope of the present paper.

2. HIGH LIFT DEVICES

2.1. Basic wing section

Before discussing methods of increasing the maximum lift coefficient of wings let us consider the lifting properties of various wing sections.

The choice of wing section for a given aircraft is always made difficult by a number of conflicting requirements. The maximum speed aimed at may call for a thin section with little or no camber; the desire to obtain low drag by means of an extensive area of laminar flow may require the maximum thickness to be placed a long way back from the leading edge. The structural experts will want thick sections in order to reduce the structure weight and their case will be supported by those responsible for stowing

large quantities of fuel and equipment within the wing. In the ensuing arguments there has sometimes been a tendency for the additional requirements for high lift coefficients to be overlooked. This is unfortunate because the basic wing section has a considerable effect on the maximum lift attainable.

This point is illustrated in Fig. 1 which shows the results of two-dimensional wind tunnel tests[1] on a N.A.C.A.64 series aerofoil section at a Reynolds number of 6×10^6. The maximum lift coefficients of the wing alone, and with a 20 per cent. chord split flap at 60°, are plotted against the thickness-chord ratio of the wing. There is a rapid increase in maximum lift coefficient as the section thickness is increased from 6 per cent. to 12 per cent. and, with the split flap fitted, this increase continues up to a thickness of about 18 per cent. Changing the design lift coefficient of the section from 0 to 0.4 increases the maximum lift coefficient by 0.24 on sections 12 per cent. thick.

The disadvantages of using high lift sections must be weighed against the difficulties of making up the loss in lift coefficient by means of more complicated flaps or other lift devices. As an example, the loss of 0.24 on the basic wing might necessitate changing the trailing edge flap from a simple split flap to the relatively complicated double slotted flap. The well known N.A.C.A.230 series aerofoils are also shown on Fig. 1, the 23012 section achieving the remarkably high lift coefficient of 1.75 without flaps.

The maximum lift coefficient of the aircraft, besides depending on the two-dimensional characteristics of the wing sections, will also be affected by the variation of wing section along the span. If the wing has a fairly high taper ratio with reducing thickness-chord ratio towards the tips, there may be a tendency for the tip sections to stall while the lift produced by the root sections is still considerably less than the maximum. With increasing incidence the loss in lift at the tips may outweigh the gain in lift at the root or, more likely, the tip stall may cause lateral instability which precludes further increase in incidence. In both cases there will be a loss in maximum lift which can amount to as much as 10 per cent.

It is worth noting here that it is equally important to prevent a premature breakdown in flow over root sections. Besides reducing the maximum lift that the wing can develop it may also introduce trim changes and a reduction in elevator power, making it impossible to reach the true stalling incidence.

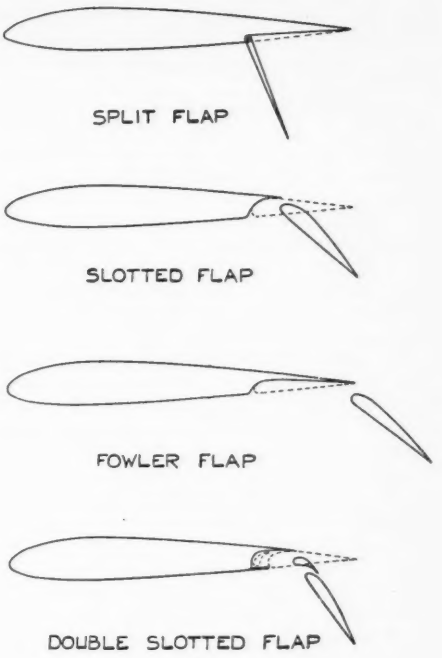

Fig. 2.

2.2. Trailing edge flaps

The use of trailing edge flaps to increase the maximum lift coefficient of the basic wing is now almost universal. The author believes that the only exceptions are either special research aircraft or light aircraft designed for private use. No attempt will be made to describe all the various forms of trailing edge flaps, ranging from the simple plain flap as used for control surfaces to the extreme double Fowler developed shortly before the war. A most useful and comprehensive review of the aerodynamic characteristics of flaps has already been given by Young.[2]

In this paper it is proposed to describe four of the most useful types of trailing edge flap, discussing their characteristics in some detail. The four types chosen are the split

flap, the slotted flap, the double slotted flap, and the Fowler (Fig. 2).

2.2.1. *Lift*

Throughout this paper the ability of a high lift device to produce lift will be measured by the increment in lift coefficient (ΔC_L) at constant incidence unless specifically stated to the contrary. The increase in maximum lift coefficient ($\Delta C_{L\,max}$) might be a more logical basis for comparison but maximum lift coefficient is very sensitive to test conditions, Reynolds number and turbulence in particular, and ΔC_L is believed to give a more accurate answer.

The split flap is probably the simplest type of flap and it increases the lift coefficient by effectively increasing the wing camber. Deflecting the flap produces a large change in no lift angle with little or no change in either lift curve slope or stalling incidence. The simple slotted flap works in a similar manner and produces about the same increase in lift coefficient. The slot introduces a stream of high energy air to the top surface of the flap and this delays the breakdown in flow over the flap. The result is that the maximum lift is produced at much lower flap deflections than with the split flap and the accompanying drag is also much less. The variation of the lift coefficient increment produced, is plotted in Fig. 3 against the flap deflection for both the split and slotted flaps.

With the split flap the maximum lift increase is usually achieved with a deflection of 70° or 80° and further deflection up to 90° produces very little change in lift. With the slotted flap the variation of lift increment with deflection depends to some extent on the method of operation. If the flap is deflected by rotating it about a fixed hinge position, which is usually below the wing surface, then it is impossible to keep the optimum slot gap for all deflections. The maximum lift is achieved at about 40° to 50° after which further deflection usually produces a considerable loss in lift. If, on the other hand, the flap is moved by a link or track mechanism then it is usually possible to keep the gap size close to the optimum. The maximum lift is again obtained at deflections between 40° and 50° but the lift at smaller deflections is greater than for the fixed hinge, and there is a much smaller loss of lift at deflections beyond the optimum.

The thickness-chord ratio of the basic wing has a considerable effect on the lift

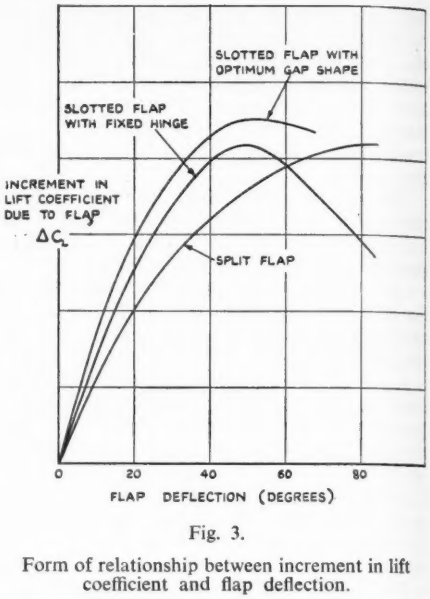

Fig. 3.

Form of relationship between increment in lift coefficient and flap deflection.

increment produced by a split flap, as can be seen in Fig. 1. A change in wing thickness from 12 per cent. to 20 per cent. increases the lift change by about 30 per cent., but with a slotted flap the same change in wing thickness produces a loss in lift of about 10 per cent. The available evidence suggests that the type of section, as distinct from the thickness, does not greatly affect the lifting properties of flaps but in the case of the slotted flap it does affect the optimum gap shape. Thus if a slotted flap is being considered for a particular aircraft, it is always necessary to obtain the results of wind tunnel tests on the optimum slot gap for a similar combination of flap and aerofoil section.

The lift increment produced by a split flap can be increased by moving the leading edge of the flap back towards the wing trailing edge. When the hinge point moves back as the flap is deflected, the arrangement is known as a Zap type flap. The increased power, which under favourable circumstances can amount to over 20 per cent., is presumably due to the rearward movement producing an effective increase in wing chord. When the flap chord is at least 30 per cent of the wing chord ($0.3c$) the greatest lift coefficient increment is obtained with the hinge $0.1c$ forward of the trailing

edge. In common with all types of flap which involve large rearward movements, the centre of pressure on the wing is also moved aft and this increases the nose-down pitching moment which will be discussed more fully in a later section.

The lifting power of a slotted flap may be increased progressively in a similar way by moving the nose of the flap towards the wing trailing edge. In the extreme position when the nose of the flap is directly under the wing trailing edge, we have the special form of slotted flap known as the Fowler. Unlike the split flap the optimum position for the flap nose is right at the trailing edge in the Fowler position. The increase in lift coefficient produced by a Fowler flap is about 30 per cent. more than that produced by a simple slotted flap of the same chord. The maximum lift increase is produced at slightly lower deflections than with the normal slotted flap, usually about 35° or 40° compared with 40° or 45°.

A device for achieving still higher lift coefficients with a Fowler flap is to fit a small split flap to the Fowler. A split flap of 0.1c fitted to a Fowler flap of 0.4c increased the maximum lift coefficient increment by 20 per cent., with only a small increase in profile drag. The deflection of the Fowler flap for maximum lift is reduced by the addition of the split flap and this partly explains the small increase in drag.

An alternative method of increasing the effectiveness of an ordinary slotted flap is to increase the deflection at which the maximum lift occurs. At an angle of about 40° or 45° the flow over the top surface of a normal slotted flap breaks down in much the same way as the flow on an aerofoil breaks down at the stall. Any further deflection of the flap produces little or no increase in lift and may cause considerable decrease in lift. With an aerofoil the stalling angle can be increased by fitting a leading edge slat and in the same way it has been found that a leading edge slat on the flap itself enables larger deflections to be used. This type of flap, usually described as a double slotted flap, has been the subject of a large number of tunnel tests in America in recent years and is now being fitted to a number of aircraft.

The maximum increase in lift coefficient produced by a double slotted flap is up to 10 per cent. more than that produced by a Fowler flap of equal chord. The maximum lift is achieved at flap deflections of about 55° or 65°. The double slotted flaps which have been tested do not make use of very large rearward movements and this is probably their chief advantage in the eyes of the structural engineer. Nevertheless, the logical development of the slotted flap would appear to be to combine the advantages of the double slotted flap with those of the Fowler flap. The resulting double slotted Fowler should produce very large lift coefficients because of the large rearward movement combined with the large deflections made possible by the double slot.

The relative merits of the four types of flaps described, judged solely on their ability to increase lift coefficient, are shown in Table I. The lift increments are estimated values based on results of two-dimensional tunnel tests for a hypothetical aircraft whose wing has an aspect ratio of ten and a thickness-chord ratio of 0.15; the assumed flap size being 30 per cent. of the wing chord and 70 per cent of the span.

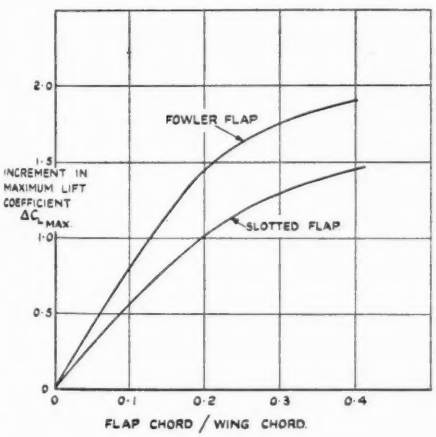

Fig. 4.
Variation of increment in maximum lift coefficient with flap chord.

Table I

Type of flap	Split	Slotted	Fowler	Double Slotted
ΔC_L	1.11	1.15	1.40	1.62
$C_{L\,max}$	2.48	2.53	2.77	2.94

The flap size in relation to the wing naturally has a major effect on the maximum lift which can be developed on a particular aircraft. The lifting power of a flap increases as the ratio of flap chord

over wing chord is increased, up to flap chords of at least 0.4*c*. Fig. 4, showing a typical variation of lift increment with flap chord, was obtained from tests on slotted flaps. The limit on flap chord in any design will probably be set by structural considerations, but it appears well worth while aiming at a flap-chord ratio of at least 30 per cent. It is also important to have the maximum possible flap span, since the lift increment due to a flap is approximately proportional to the ratio of area of wing in front of the flap to total wing area. Normally the flap span is limited by the ailerons, but if maximum lift is an important factor in a particular design, then increases in flap span should certainly be considered even if it means adopting a slightly unorthodox lateral control.

In most cases flap spans of 70 per cent. or 75 per cent. of the wing span can be accommodated simply by changing the aileron shape from the usual narrow chord and long span to wide chord and short span. A full span flap can be obtained without altering the normal aileron configuration by fitting a split flap in front of the aileron. Such a scheme may be expensive in drag but the results of model tests are encouraging and it proved quite satisfactory when tried out in flight on a lightly loaded aircraft. If a full span slotted flap is required then either the aileron must be situated in the flap itself, as on the Supermarine Seagull, or else an alternative form of lateral control, such as lift spoilers, must be used. Satisfactory results have been obtained in flight on a number of aircraft with ailerons inset in the flap but the angular deflection of the outboard portion of the flap has to be restricted to retain adequate aileron power. With the lateral control supplied by a lift spoiler on the top surface of the wing, there is unlikely to be a restriction on flap deflection due to lack of rolling power. Although the use of lift spoilers for lateral control has never been entirely satisfactory, the possibility of using power operation certainly increases the chances of success in the future.

2.2.2. *Drag*

The increment in profile drag coefficient caused by a trailing edge flap is often no less important than the increment in lift coefficient, particularly on civil aircraft which have to meet stringent climb requirements. In this Section the profile drag of the four flaps already considered will be compared on the basis of two-dimensional tunnel tests. These results will not be

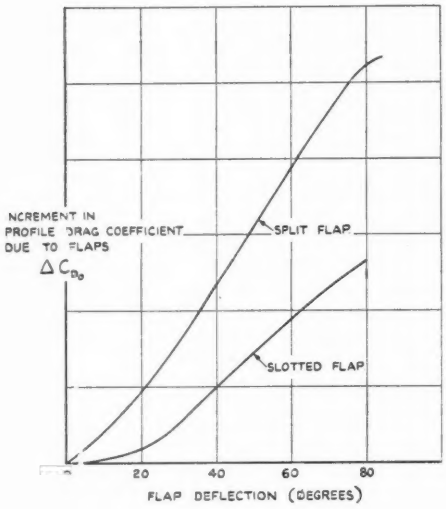

Fig. 5.

Form of relationship between increment in profile drag coefficient and flap deflection.

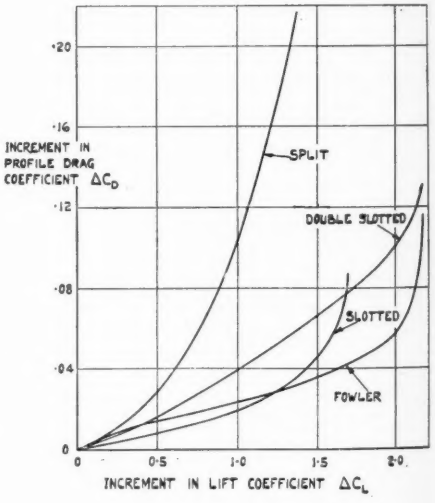

Fig. 6.

Variation of increment in profile drag coefficient with increment in lift coefficient for various flaps.

directly applicable to flap installations on aircraft because of major interference effects at the wing-fuselage and wing-nacelle junctions. Nevertheless, it is suggested that the two-dimension tests do give a true comparison between the flaps and the interference effects will be discussed in the next Section.

The split flap produces its maximum lift when the angle between the flap and the top surface of the wing is large (60° or 70°) and this gives a wide wake and therefore, high drag. With the slotted flap the maximum lift is obtained at much lower deflections (about 40°) and the flow of air through the gap prevents serious separation of flow from the top surface of the flap. The resulting wake is much narrower and the drag is much lower. The form of the relationships between profile drag coefficient and flap deflection for split and slotted flaps are shown in Fig. 5. The curves show that the slotted flap has less than half the profile drag of the split flap even when compared at equal angles; a comparison will be given later at equal lift increments which shows the slotted flap to even greater advantage. The low drag of the slotted flap is particularly marked up to angles of 20°; above 30° the rate of increase in drag with flap deflection is much greater, but is only about half that of the split flap.

When comparing the actual increments in profile drag coefficient of a number of different flaps it is important that the wing section and test conditions should be identical. Unfortunately it is not often that there are sufficient data to make this possible but the split, slotted, double slotted and Fowler flaps have all been tested on an NACA.23012 aerofoil at a Reynolds number of 3.5×10^6. The tests were made in a wind tunnel on a two-dimensional wing and the results shown in Fig. 6 are for flap chords of $0.3c$; the increments in lift and drag coefficients being measured at 6° incidence above the no lift angle of the datum wing.

In each case the rate of increase of drag coefficient with lift coefficient increases rapidly at the higher lifts where the flap deflections are large. Comparing the drags at constant lift increment it is seen that, above a ΔC_L of 0.6, the slotted flap has less than a quarter of the drag of the split flap. The Fowler flap has rather more drag than the slotted flap at low lift increments, due probably to the large rearward travel which occurs in the initial movement of the Fowler. This produces a considerable increase in lift but the extra wetted area, accompanied possibly by an inefficient slot, makes the drag higher than the simple slotted flap. There is some evidence that the drag in this initial phase of the movement can be reduced by keeping the slot closed until the flap is fully extended and deflected to an angle of about 15°.

Above a lift coefficient increment of 1.25 the Fowler flap is superior to the slotted flap and it continues to operate efficiently up to a ΔC_L of 2.0. The extra slot in the double slotted flap causes a considerable increase in drag throughout the range of lift increments. Up to a lift increment of 1.0 it has approximately twice the drag of a slotted flap but at the maximum lift increment it has only slightly more drag than the Fowler. The minimum drag is obtained by making a suitable choice between a Fowler or a slotted flap, depending on the lift increment required and this minimum drag is little more than half that of the double slotted flap up to a ΔC_L of 2.0.

2.2.3. *Interference*

In most aircraft it is impossible to avoid interrupting the flap span at one or more points. The fuselage usually constitutes the major break and on many aircraft the flap is interrupted again by the engine nacelles. At each junction it is always difficult, and sometimes impossible, to provide a clean aerodynamic design with flaps down. Unfortunately, the wing-fuselage and wing-nacelle junctions are notoriously sensitive; quite small disturbances can cause considerable changes in both lift and drag. The nature of these interference effects is clearly very complex and the lift and drag changes cannot be predicted with any accuracy. The best that can be done is to give rough qualitative guides to the sort of interference effects which may be expected.

The effect on the lift increments of flaps is usually to decrease the lift but the changes are not as large as might be expected. With both split and slotted flaps the lift increment can be predicted with reasonable accuracy from two-dimensional data, provided that due allowance is made for cut-outs. It is suggested that slotted flaps will always be more sensitive than split flaps because of the importance of maintaining the optimum flow through the gap. There is some evidence suggesting that with low wing

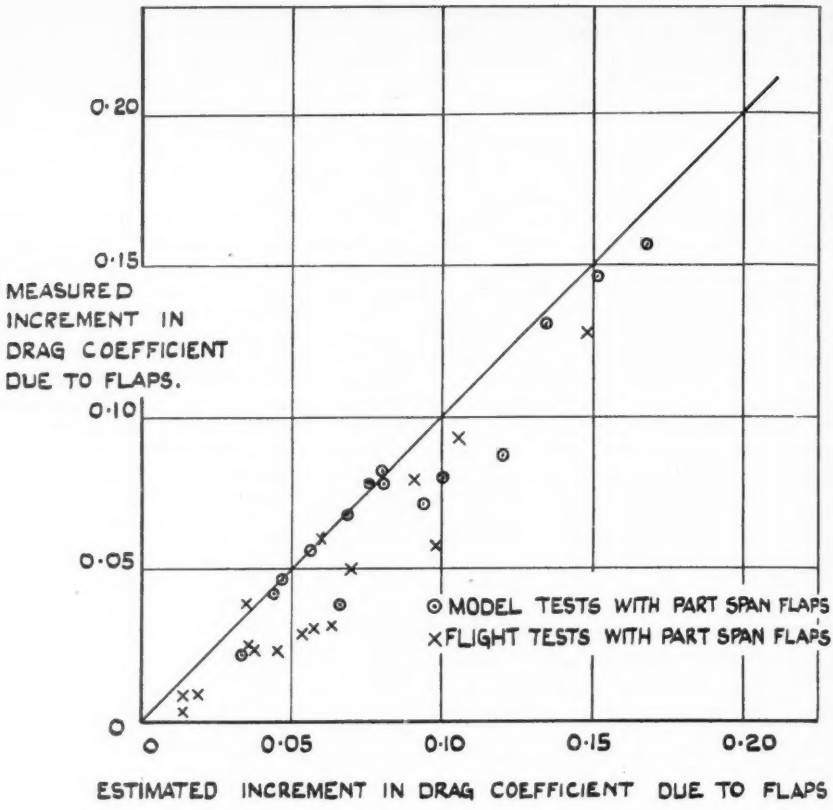

Fig. 7.

Comparison between measured and estimated increments in profile drag coefficient due to split flaps.

positions the cut-out in the flap under the fuselage should be kept as small as possible. In one particular case of a low wing aircraft with a Fowler type flap and a large cut-out under the fuselage, the lift was increased and the drag decreased by filling up most of the cut-out with a simple split flap. If the flap must be interrupted by either fuselage or nacelles it is probably best to have a high wing position and underslung nacelles. In these cases measured lift increment appears to be about half way between the value estimated by taking full account of the cut-outs and the value estimated, assuming no cut-out.

The interference effects on drag appear to be more pronounced than the effects on lift. On split flaps the interference reduces the drag but on slotted flaps the drag is usually increased, although in a limited number of the cases considered it was reduced. If the drag of a particular flap installation is estimated from two-dimensional data, or from tests on wings alone, and if this value is compared with results of flight tests or wind tunnel tests on the complete model, then it is assumed that the difference gives a measure of the interference drag. No great accuracy can be expected from this method because it includes the errors involved in drag estimation but the results are still of interest and if sufficient cases are considered they do show the trend of the interference effect.

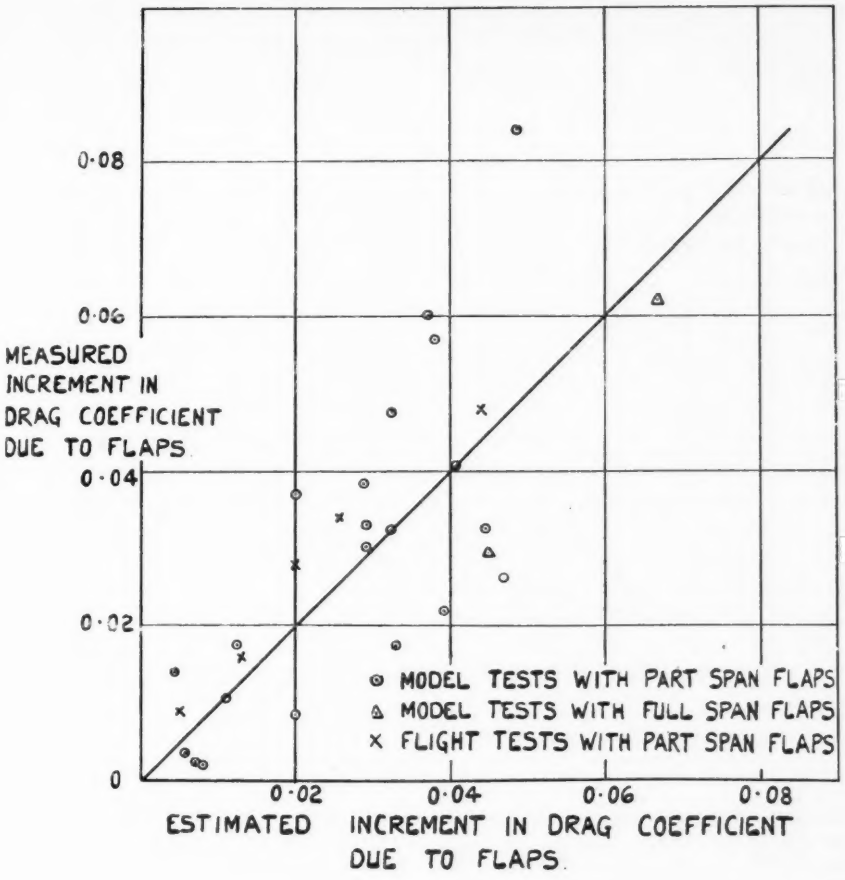

Fig. 8.

Comparison between measured and estimated increments in profile drag coefficient due to slotted flaps.

In Figs. 7 and 8 the measured flap drag from both wind tunnel and flight tests have been plotted against the estimated drag for split and slotted flaps. The results with split flaps in Fig. 7 show that the measured drag is nearly always less than the estimated value, leading to the conclusion that the interference effect is favourable. It has been suggested that this may be due to cleaning up the flow in the wing-fuselage or wing-nacelle junctions as a result of the modified pressure distribution caused by deflecting the flap. If this is the case, then the interference would be expected to have least effect on a basically clean design. In Fig. 8 results of tests on all types of slotted flap are included and no distinction is made between them; the scatter is very large but the measured drags are usually greater than the estimated values. It is worth noting that full span flaps gave less than the estimated drag and a similar result was obtained on one high wing aircraft with part span flaps. In both cases the flaps were uninterrupted by engine nacelles.

Finally in Fig. 9 the measured increment in profile drag coefficient has been plotted against the measured increment in lift

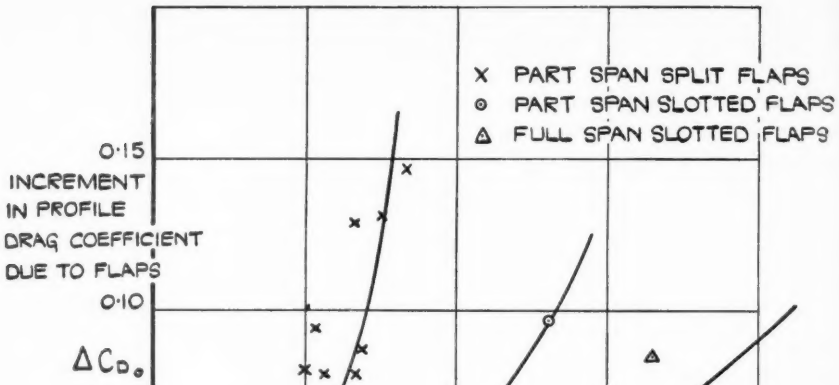

Fig. 9.

Relationship between the increments in lift and drag coefficient for split and slotted flaps.

coefficient. Although there is considerable scatter in the points it is possible to divide them into three main groups, split flaps, part span slotted flaps, and full span slotted flaps. Once again the slotted flaps include both the Fowler and double slotted types as well as the simple slotted flap. The split flaps normally give considerably more drag than the slotted flap for equal lift increments, but in some cases, particularly at low lift increments, with favourable interference on the split flap and large adverse interference on the slotted flap, there is little to choose between the two types. This result may be expected on low wing aircraft with short flap spans interrupted by large nacelles.

Nevertheless, it is probably true to say that, whatever the type of installation, the probability of achieving a low drag increment is always greater with a slotted flap than with a split flap. At lift coefficient increments of more than 0.5 the slotted flap will certainly give considerably less drag than a split flap. If lift increments of 0.75 and over are required then full span slotted flaps should be carefully considered, for the evidence suggests that they have less than half the profile drag of part span flaps for the same lift increase.

2.2.4. *Pitching moments*

It has been shown by Glauert[3] that the theoretical pitching moment coefficient due to a flap is always a nose-down moment and is directly proportional to the increment in lift coefficient. This theory is closely borne out in practice and the following ratios between increments of pitching moment coefficient (ΔC_m), and lift coefficient (ΔC_L) have been given by Young[2]. The values are approximations only but are sufficiently accurate for comparative purposes.

Type of flap	Split	Slotted	Double Slotted	Fowler
$\Delta C_m/\Delta C_L$	−0.25	−0.33	−0.33	−0.43

The increased pitching moment with slotted flaps compared with the split flap is due to the rearward movement and an increase in the proportion of the load carried by the flap itself.

(i) *Change in trim*

These pitching moments are not troublesome in themselves but they can have a large influence on the change in trim experienced by the aircraft when the flaps are moved. It is believed that the possibility of large trim changes is one of the chief deterrents tending to prevent designers making use of high lift flaps. Consideration of how changes in trim are influenced by increments in pitching moment is therefore well worth while.

It is necessary to start by defining what is meant by change in trim. Three possible definitions are: "the change in elevator angle necessary to maintain trim when the flaps are moved keeping either (*i*) constant incidence, (*ii*) constant lift coefficient, or (*iii*) a constant ratio between the lift coefficient and the maximum lift coefficient with the corresponding flap deflction." It is suggested that the first definition would be quite artificial and that the true flight case lies somewhere between definitions (*ii*) and (*iii*). With moderately rapid flap movement the flight case will approximate closely to a change at constant lift coefficient but with normal rates of movement it is suggested that definition (*iii*) is the better compromise and this will be used in the following arguments.

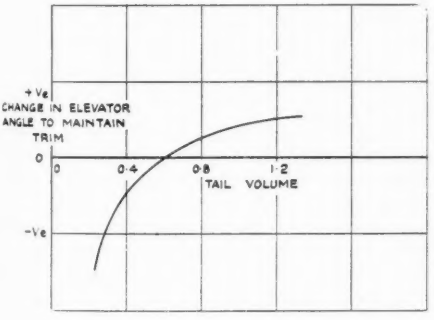

Fig. 10.

Form of relationship between tail volume and the change in elevator angle required to maintain trim on deflecting the flaps.

The change in trim results from two opposing effects:—

(*i*) the change in pitching moment on the wing as the flaps are deflected which gives a nose-down moment and

(*ii*) the increase in downwash over the tailplane which gives a nose-up moment.

For a given type and size of flap the change in elevator angle required to trim out the pitching moment on the wing will be inversely proportional to the tail volume, assuming that the size of elevator relative to the tailplane remains constant. The bigger the tail the smaller is the elevator angle required to give a particular pitching moment. The elevator angle required to trim out the downwash effect will be nearly independent of tail volume. In fact, the relation between change in elevator angle required to trim ($\Delta\eta$) and the tail volume ($\overline{V}$) will be of the form

$$\Delta\eta = A - B/\overline{V}$$

where A is a constant depending chiefly on the elevator characteristics and position of tailplane,

B is a constant depending chiefly on the type and size of flap,

and $\overline{V}$ = tail volume =

$$\frac{\text{tail area} \times \text{tail arm}}{\text{wing area} \times \text{mean chord}}$$

This relationship is shown diagrammatically in Fig. 10. As the tail volume is increased the trim change on lowering flaps alters from a nose-down change to a nose-up change and thus it is theoretically possible to design for zero trim change by a suitable choice of tail volume. Unfortunately, tail volume is determined by stability requirements with the result that it is often difficult to avoid changes in trim due to flaps.

It is impossible to generalise on the precise trim change which will be experienced with any particular flap because it depends on the geometry of the aircraft, as well as on the tail volume. However, it was considered to be of sufficient interest to justify estimating the trim change on a hypothetical aircraft for a series of different high lift flaps over a range of tail volumes. The aircraft chosen had a conventional layout and the flaps ranged from a 50 per cent. span split flap giving a ΔC_L of 0.5 to a full span Fowler giving a ΔC_L of 1.8. The results of these estimates are given in Fig. 11,

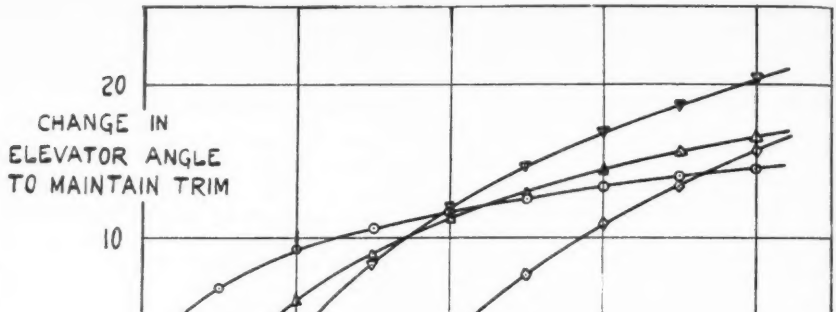

Fig. 11.

Relation between change in elevator angle to maintain trim and tail volume for various types of flap.

the shape of the curves being similar to that suggested in Fig. 10. At the tail volume needed for adequate stability, probably about 1.0, the trim change will be in the nose-up direction and there is surprisingly little variation between the various types of flap.

It is interesting to note that the flaps which give the smallest trim change are those with the largest pitching moment change. This is because at high tail volumes the downwash effect is larger than the effect due to the pitching moment on the wing and thus the higher the wing pitching moment, the smaller the trim change. With large tail volumes a large span flap will have a smaller trim change than a small span flap because, for a given total lift coefficient the downwash over the tail will be less. The values obtained for the elevator angles to trim are rather larger than usually measured in flight. This is thought to be due to inaccuracy in estimating the downwash, but the form of the curves and the comparison between the different types of flap should be correct.

In addition to these changes in trim due to the flap there are further trim changes due to slipstream. These are usually in a nose-up direction with increasing power, but unfortunately it is not yet possible to predict them with sufficient accuracy. They can be large, particularly when large flaps are fitted, and although keeping the tailplane as high as possible will probably minimise the effects, there is a case for fitting an adjustable tailplane on high lift aircraft.

(*ii*) *Ground effect*

In the past when high lift flaps have been fitted to aircraft with only moderate tail

volumes, troubles have sometimes occurred during take-off and landing through having insufficient elevator power. This is caused by the effect of the ground, which alters the trim of the aircraft in three ways:—

(*i*) by altering the pitching moment on the main plane,

(*ii*) by altering the lift on the tailplane at a given incidence, and

(*iii*) by altering the downwash over the tailplane.

Of these three the first is relatively unimportant and can be ignored, but the second and third can be of equal importance. The alteration in downwash is usually the largest factor but the change in lift on the tail can be quite large for aircraft with low tails. Taking the hypothetical aircraft already considered the total ground effect on trim was estimated for a range of flaps. The resulting change in elevator angle required to trim has been plotted against height of the main plane above the ground in Fig. 12. The maximum difference between the various types of flap only amounted to $1\frac{1}{2}^{\circ}$ of elevator movement and the curve shown is a mean for all types. The effect of the ground falls off quite rapidly as height is increased but when the aircraft is on, or only just off the ground, during take-off for example, or while holding off before touchdown, then the trim change can amount to about 15° of elevator. Elevator movements of this order are usually well within the capabilities of most aircraft, provided that a large amount of up-elevator travel has not already been used to trim out the flap effects. It is suggested that by using tail volumes of about 1.0 there will be a nose-up change in trim due to flaps, thereby giving greater elevator travel to deal with the change in trim caused by ground effects.

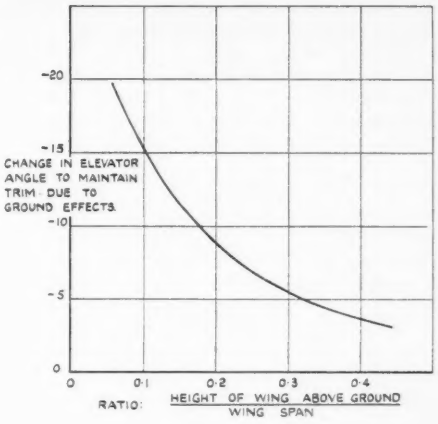

Fig. 12.

Variation of elevator angle to maintain trim as aircraft approaches the ground.

(*iii*) *Loss in lift due to trimming*

Another argument which has often been used to make a case against flaps with large pitching moments is that the gain in maximum lift is considerably reduced by the down load on the tail required to trim the aircraft. Here again it appears that the influence of tail volume has been overlooked to some extent. The lift required from the tailplane to trim the aircraft can be seen at once from the standard pitching moment curves in which the pitching moment coefficient without tail is plotted against the lift coefficient. A typical pair of curves is shown in Fig. 13. With flaps up the stalling lift coefficient is represented by the point *A* and with flaps down the maximum lift coefficient becomes point *C*. The ordinate *AB* represents the tailplane lift to trim flaps up and the ordinate *CD* similarly represents the tail lift to trim flaps down. In the case shown since *CD* is greater than *AB*, there will be a gain in maximum lift coefficient due to trimming. It can easily be shown that the approximate change in maximum

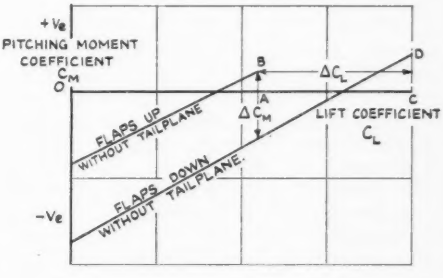

Fig. 13.

Typical variation of pitching moment coefficient with lift coefficient for complete aircraft minus tailplane.

lift coefficient due to trimming out the pitching moment of the flap is given by

$$\Delta C_{L\,trim} = \frac{\Delta C_L(h-a) + \Delta C_M}{l/c}$$

where ΔC_L = increment in maximum lift coefficient due to the flap

ΔC_M = increment in pitching moment coefficient due to the flap

l/c = ratio of tail arm to mean wing chord

and $h-a$ = distance of C.G. behind the aerodynamic centre of the aircraft without tail in terms of the mean chord.

Taking once more the hypothetical aircraft with its various types of flaps, the change in maximum lift coefficient due to trimming can be estimated from the above formula for a range of tail volumes, assuming a constant degree of longitudinal stability and a constant tail arm. The gain in lift coefficient due to trimming out the pitching moment due to flap has been plotted in Fig. 14 against the tail volume. This shows that with a tail volume of 0.6 there is a considerable loss in lift due to trimming with very high lift flaps but when the tail volume is increased to 1.0 there is a small gain in lift for all except the largest type of flap and even in this case the loss is quite small.

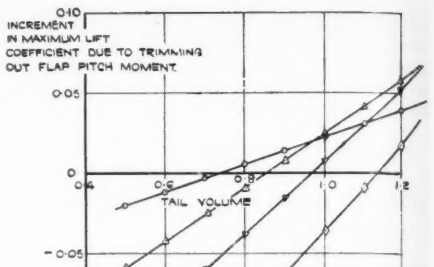

Fig. 14.

Variation of increment in maximum lift coefficient, due to trimming out flap pitching moment, with tail volume for various types of flap.

2.2.5. *Stability*

Trailing edge flaps can alter the longitudinal stability of an aircraft in two ways:—

(*i*) by altering the rate of change in downwash with incidence, or

(*ii*) by altering the rate of change of wing pitching moment with lift coefficient.

The first effect, caused by change in downwash, depends chiefly on the position of the tailplane relative to the wake from the wing, the lift increment caused by the flaps and the percentage span of the flaps. A range of flaps from a 50 per cent. span split to a full span Fowler, were considered for one particular aircraft and estimates of the rate of change of downwash with incidence showed little variation between the various types of flap, but it was always greater than the estimated value for the basic wing. This effect is destabilising and in the case considered amounted to a forward movement of the neutral point of about 6 per cent. of the mean chord; increasing the height of the tailplane would probably reduce this destabilising effect.

The alteration in rate of change of pitching moment on the wing itself is usually stabilising, but the evidence suggests that the magnitude of this stabilising effect gets smaller as incidence and flap deflection are increased. The increase in stability is directly associated with rearward movement and therefore is most marked with slotted flaps that involve large rearward movements, such as the Fowler.

The flight evidence suggests that the overall effect of flaps on stability is usually small, but with a tendency towards increased stability. In general, the flap effect is of minor importance compared with the effects of slipstream. An analysis by Morris and Morrall[4] suggests that the flaps can produce large changes in the slipstream contribution to stability by altering the relative position of the tailplane to the wing wake. By a suitable choice of tailplane position it appears possible to make the destabilising effect of slipstream very much less with flaps deflected than with flaps retracted.

2.2.6. *Structure*

As already stated, the structural and mechanical problems involved with the

various types of flaps are unfortunately outside the scope of this paper, but since the accuracy of construction sometimes has an important influence on the performance of the flaps, this aspect will be discussed briefly here.

With the simple split flap no great accuracy in construction is called for, since the hinge position and angular deflection are the only variables and small errors in either of these will have little effect on the lift and drag properties of the flap.

With all types of slotted flap small changes in the hinge position, or errors in the track or link operating mechanism, can cause considerable variation in the shape and size of the slot. When slotted flaps are giving their maximum lift increment the flow on the top surface of the flap is prevented from breaking down by the high energy air stream introduced by way of the slot and if this slot is not of the optimum shape and size the flap may stall, causing serious loss in lift and increase in drag. The various types of slotted flap differ in their sensitivity to variations in slot shape. In Table II the loss in lift coefficient is shown for a movement of the nose of the flap equal to half a per cent. of the wing chord.

TABLE II

Type of flap	Single Slotted	Fowler	Double Slotted
Loss in lift Coefficient	0.15	0.12	0.22* 0.30†

*Front slot. †Rear slot.

The double slotted flap, besides having two slots to go wrong, appears to be particularly sensitive to the size of the slot gaps. When using this type of flap, therefore, it is most important to ensure accurate positioning of the flap and to provide plenty of stiffness in the slot since this will be subjected to high loads. Normal force coefficients of up to 5 have been measured on the slat of double slotted flaps.

2.3. Leading Edge Slats

It will be shown in a later Section that for certain types of aircraft the take-off and climb requirements make it particularly important to provide high lift at low drag. One of the most effective methods of doing this is by using a full span leading edge slat.

The slat provides extra lift by delaying the breakdown in flow on the top surface of the wing, and the $C_L - \alpha$ curve for the wing without slat is simply extended, with little or no change in slope, to a new stalling incidence some 10° higher. To obtain the best advantage from a leading edge slat it is essential that it should be full span and it is most important that possible gaps, such as between the slat and the fuselage, should be carefully sealed.

An analysis by Young[5] led to the suggestion that the increment in maximum lift coefficient ($\Delta C_{L\,max}$) due to a leading edge slat can be estimated approximately by taking

$$\Delta C_{L\,max} = 3.3 \text{ slat chord/wing chord.}$$

More recent measurements during tests in wind tunnels and in flight, support this simple relationship. The normal slat chord is between 15 per cent. and 30 per cent. of the wing chord and the corresponding increments in maximum lift coefficient range from 0.5 to 0.9. The associated increases in profile drag are remarkably small, usually less than 0.01 and they therefore compare favourably with slotted flaps. It must be remembered, however, that the increment in lift is only obtained by operating at higher incidences and the low drag of the slat may be offset in some cases by an increase in profile drag of the wing and fuselage.

During take-off and landing, to make full use of the high lift coefficients obtainable by a leading edge slat, it must be possible to reach large incidences while on the ground. The actual incidence required will vary with the aspect ratio of the wing from about 18° to 20° for an aspect ratio of 6, down to 14° to 16° for an aspect ratio of 10. The large angles required at low aspect ratios may necessitate a variable incidence wing, but at high aspect ratios there is a fair chance of attaining sufficient incidence with a suitably shaped fuselage and moderately long undercarriage oleos.

Because a leading edge slat effectively increases the wing area forward of the centre of pressure, it produces pitching moments of opposite sign to those produced by trailing edge flaps. This may be advantageous in certain cases but unfortunately the forward shift of the centre of pressure also causes a reduction in the longitudinal stability. This destabilising effect can be very large and in one case it corresponded to a change in C.G. position of 12 per cent. of the mean wing chord.

With a leading edge slat in the closed position it would probably be very difficult

to get laminar flow farther back than the aft end of the slat. This would limit the laminar region to about 20 per cent. chord on the top surface and about 5 per cent. chord on the bottom surface. It is also probable that de-icing of the leading edge would be made more difficult by the presence of a slat.

2.4. Boundary Layer Control

Slotted flaps and leading edge slats produce high maximum lift coefficients by what may be described as natural boundary layer control. Much higher maximum lift coefficients can be achieved by increasing the rate of flow through the slot gaps but this requires additional energy and may be described as forced boundary layer control.

The numerous wind tunnel tests which have been made suggest that the maximum lift coefficient attainable is approximately the same whether air is sucked away from the boundary layer or blown into it. One of the most promising methods consists of blowing air along the top surface of a plain flap from an exit above the flap hinge. The increment in lift coefficient is roughly proportional to the quantity of air ejected and the results of two-dimensional wind tunnel tests at Reynolds numbers of about 1×10^6 show that the increment in local lift coefficient, ΔC_L, can be taken as

$$\Delta C_L = 75\ Q.V./S$$

where Q = quantity of air passing through the slot in cu. ft./sec.

V = free stream velocity in ft./sec.

and S = wing area subjected to boundary layer control.

Suppose now that high lift coefficients by boundary layer control are required on a four-engined civil aircraft with an all-up weight of 80,000 lb. and a wing loading 45 lb./sq. ft. The best arrangement would probably be to use a 70 per cent. span plain flap of 25 per cent. chord and to eject air at the hinge position. The increment in maximum lift coefficient is shown in Fig. 15 against the quantity of air per second which must be ejected. The quantity required to give a lift coefficient increment of 1.0 would prove quite impracticable, but this picture may be unduly pessimistic since it is based on tunnel tests at low Reynolds number. It has been suggested that the quantity of air which must be ejected to produce a given

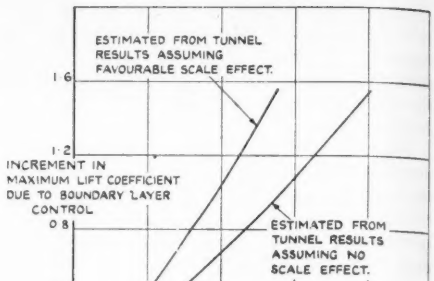

Fig. 15.

Variation of increment in maximum lift coefficient with quantity of air used for boundary layer control.

increment in lift coefficient is directly proportional to the thickness of the turbulent boundary layer. This has not been verified by experiment, but if it is true there will be a favourable scale effect on the quantity of air required since the thickness of the boundary layer will be approximately proportional to Reynolds number to the power -0.15. The magnitude of this favourable scale effect is shown in Fig. 15.

Air compressors will be necessary to force the air through the slots and in order to reduce the added weight it is desirable to keep the quantity of air to be handled by these compressors down to a minimum. This quantity can be halved by using the same air twice; sucking in air from the boundary layer over one spanwise portion of the flap and blowing it out over another. The compressors would probably be driven by the aircraft's engines and it is of interest to compare the quantities of air required for high lift with the maximum air consumption of a turbine engine, typical for the type of aircraft considered. These results are also shown on Fig. 15; an increment in lift coefficient of 1.0 requires a minimum quantity of 0.45 times the maximum consumption of the engines.

It is suggested that the quantities which must be ducted through the wing to produce worth-while increments in lift coefficients are still too large to be practicable. In addition it is doubtful if there would be sufficient power available to drive a boundary layer control scheme and at the same time meet the stringent climb requirements with one engine inoperative.

There was a possibility that boundary layer control might be economical for the Army co-operation aircraft which has to operate from confined spaces and can have a low wing loading. A detailed performance investgation[6] made in America shows, however, that even for this class of aircraft a better performance can be obtained by conventional high lift devices such as flaps and slats.

It is possible that boundary layer control may become worth while if it is used to deal with a laminar boundary layer. Preventing the laminar separation near the leading edge of an aerofoil involves very much smaller quantities of air than the control of turbulent flow over a trailing edge flap.

2.5. SLIPSTREAM

All aircraft with propellers get a substantial increase in lift coefficient due to the slipstream passing over the wing and flaps.

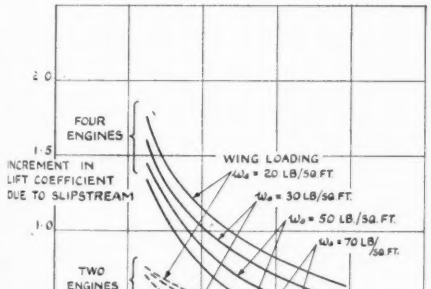

Fig. 16.

Variation of increment in lift coefficient due to slipstream with power loading.

This increase in lift coefficient is a function of engine power and of forward speed and is greatest at maximum power and low speed. To illustrate the amount of this lift increment, estmates have been made for aircraft of conventional layout. The aircraft were assumed to have tractor propellers and a maximum lift coefficient of 2.0 with flaps set for take-off and with zero power. The estimated increase in lift coefficient at take-off speed is plotted against power loading in Fig. 16 for twin, and four-engined aircraft for a range of wing loadings. These curves are merely intended to illustrate the order of slipstream lift to be expected and should not be taken as generalised curves for estimation purposes.

The increment in lift coefficient with four engines is approximately double the effect produced with two engines and is about equal to the lift increment produced by normal sized flaps. These large increases in lift considerably reduce both the minimum take-off speed and the minimum ground run during take-off. On civil aircraft the take-off distance is determined to a large extent by the safety climb speed and this is laid down in both national and international airworthiness regulations as a function of the aircraft stalling speed with power off. Thus the lift increment due to slipstream cannot be used to reduce the overall take-off distance, but it does improve the control of the aircraft during take-off by increasing the margin between climbing incidence and stalling incidence. On military aircraft operating from aerodromes the conditions are similar to civil operations, but with aircraft operating from aircraft carriers minimum ground run is the important factor and the slipstream lift is a great help towards keeping this within the very limited lengths available.

During landing the air speed is approximately equal to the take-off speed but the power used is very much less, probably about one-third. The slipstream increment in lift coefficient during the landing approach is between a quarter and a third of that developed at take-off. Here again, it helps both to reduce the landing speed and increase control and these beneficial effects are most noticeable on carrier-borne aircraft because of the necessity to keep landing speeds to a minimum. The slipstream lift is particularly beneficial in the event of a balked landing, provided that it is not accompanied by large trim changes.

2.6. Jet deflection

Aircraft employing pure jet propulsion usually experience little change in lift coefficient with variation of thrust, but it has been suggested that considerable gains in lift are possible by deflecting the jet stream at a large angle to the flight path. This proposal may be acceptable on aircraft with very high thrust weight ratios, such as with high performance fighters, in which some of the thrust can be sacrificed to provide lift while still maintaining sufficient thrust to give a reasonable rate of climb.

It has been estimated that with a thrust weight ratio of 0.4 a jet deflection of 60° might be obtained, giving an equivalent increase in lift coefficient of 0.2 for landing, increasing to 0.4 at full throttle in the event of a balked landing. A device of this sort would be particularly attractive for some military aircraft on which lift increments cannot easily be obtained by more normal means.

3. USES OF HIGH LIFT DEVICES

3.1. During take-off

The normal measure of the take-off performance of an aircraft is the distance required to accelerate from rest to the climbing speed, plus the distance required to climb up to a height of 50 ft. This overall distance determines the size of aerodrome required to operate a given aircraft at a given weight. If the take-off distance at maximum weight is greater than the size of aerodrome available, then the take-off weight of the aircraft will have to be reduced by sacrificing either payload or range. To operate aircraft at their maximum efficiency, therefore, it is vitally important that their take-off distance at maximum weight should be kept within the limits of existing aerodromes. In the past the length of runways has been steadily increasing but it is doubtful if much additional increase can be expected because of the rapid rise in cost of construction, both in labour and in material. The designers of civil aircraft in particular will have to concentrate on keeping down the take-off distance of their aircraft and it is suggested that the use of high lift devices will be essential for this purpose.

The distance required by an aircraft to accelerate from rest to climbing speed is approximately proportional to the square of the climbing speed, or inversely proportional to the maximum lift coefficient. The drag of the aircraft during this stage is of only secondary importance. The distance covered during the climb to a height of 50 ft., however, is chiefly dependent on the difference between the thrust and the drag.

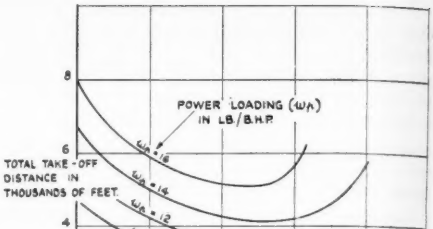

Fig. 17.

Variation of total take-off distance with maximum lift coefficient for a range of power loadings with all engines operating.

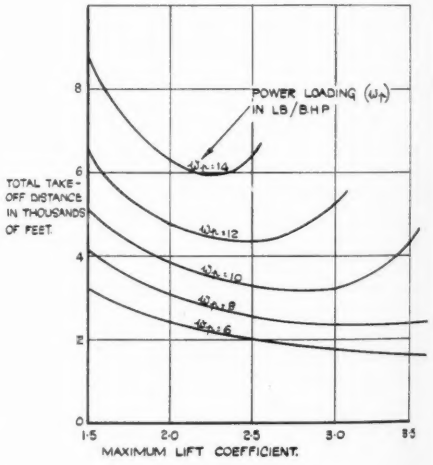

Fig. 18.

Variation of total take-off distance with maximum lift coefficient for a range of power loadings when one engine out of four fails at the start of the climb.

If the maximum lift coefficient of an aircraft in the take-off condition is steadily increased the drag coefficient will also be increased, partly because of the profile drag of the lift device but mainly because of an increase in the induced drag. Thus with increasing maximum lift the distance covered during acceleration will be reduced, but the distance covered during the climb to 50 ft. will be increased. Because the induced drag is proportional to the square of the lift coefficient the distance covered during the climb increases rapidly at high lift coefficients. The net result is that, initially, increasing maximum lift coefficient causes large reductions in the overall take-off distance, but the rate of reduction gets less and less and there will be some optimum maximum lift coefficient beyond which an increase in lift will cause an increase in the total distance.

To illustrate the reductions in take-off distance which may be expected due to increasing the maximum lift coefficient, estimates have been made for a conventional type of propeller-driven aircraft with an aspect ratio of 10. One of the chief assumptions which must be made concerns the variation of drag with maximum lift coefficient; the values taken imply that the best possible use is made of high lift devices. The drag figures together with other relevant particulars are given in the Appendix. In Fig. 17 the take-off distance has been plotted against the maximum lift coefficient for a range of power loadings at a constant wing loading of 50 lb./sq. ft. The maximum lift coefficients in this, and the succeeding figures, refer to the take-off condition with power off. It is emphasised that these curves are not intended to give generalised results for estimation purposes; they simply illustrate the type of result to be expected.

When the power loading is low, 6 lb./B.H.P., increasing maximum lift coefficient continues to reduce the take-off distance up to at least a $C_{L\,max}$ of 3.5. The distance then is only half the distance required at a maximum lift coefficient of 1.5. At a power loading of 10 lb./B.H.P. there is little to be gained by using maximum lift coefficients greater than 3.0 and at a power loading of 16 lb./B.H.P. the optimum value is reduced to about 2.6. Using these optimum maximum lift coefficients the reduction in take-off distance due to the flaps is 47 per cent. at a power loading of 10 lb./B.H.P. and 36 per cent. at a power loading of 16 lb./B.H.P.

So far it has been assumed that full power is used throughout the take-off, but to satisfy the highest airworthiness requirements one

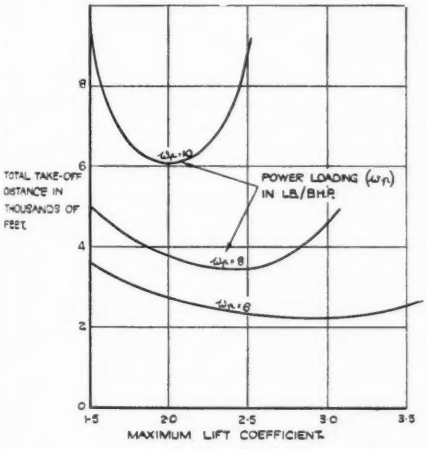

Fig. 19.

Variation of total take-off distance with maximum lift coefficient for a range of power loadings when one engine out of two fails at the start of the climb.

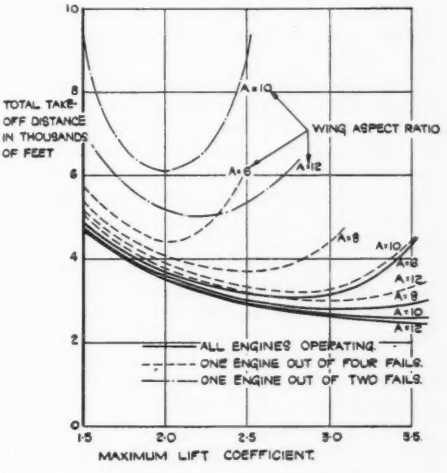

Fig. 20.

Variation in total take-off distance with maximum lift coefficient for a range of aspect ratios.

TABLE III

Power Loading (lb./B.H.P.)		6	8	10	12	14	16
All engines operating	Optimum $C_{L\,max}$	>3.5	>3.5	3.5	3.2	2.85	2.6
	Percentage reduction in take-off distance	52	50	47	44	39	36
One engine out of four fails	Optimum $C_{L\,max}$	>3.5	3.1	2.8	2.45	2.25	—
	Percentage reduction in take-off distance	49.2	43.2	39.5	35.3	32.5	—
One engine out of two fails	Optimum $C_{L\,max}$	2.9	2.4	2.0	—	—	—
	Percentage reduction in take-off distance	38.8	32	35	—	—	—

engine must be assumed to fail at some critical point during the take-off. For the purposes of illustration this critical point for engine failure is assumed to be directly the aircraft reaches the climbing speed. When the engine fails there is assumed to be a sudden increase in drag due to the windmilling propeller, which is assumed to remain unfeathered until after reaching a height of 50 ft. The loss in thrust and increase in drag naturally cause a large reduction in the rate of climb and the effect on the optimum maximum lift coefficient for take-off is similar to an increase in the power loading. The take-off distance has been plotted against maximum lift coefficient, assuming engine failure at the critical point, in Fig. 18 for four-engined aircraft with a wing loading of 50 lb./sq. ft. Comparing these results with those obtained with all engines operating, it is quite clear that the optimum maximum lift coefficients are considerably reduced, particularly at the higher power loadings. For example, at a power loading of 12 the optimum $C_{L\,max}$ is reduced from 3.0 down to about 2.45 due to the engine failure. At a power loading of 16 the reduction in thrust and increase in drag are so serious that the aircraft can no longer climb.

With twin-engined aircraft the performance after one engine has failed is considerably lower than with a four-engined aircraft, because the reduction in thrust is a much greater percentage of the total. The effect of this is that high maximum lift coefficients for take-off can only be afforded if the power loading is low. The take-off distances are plotted against maximum lift coefficients in Fig. 19. A maximum lift coefficient of 3.0 is worth while at a power loading of 6 lb./B.H.P., but at a power loading of 10 lb./B.H.P. the optimum value is reduced to 2.0. At power loadings greater than 10 the climb becomes impossible in the particular case considered.

These results are summarised in Table III which gives the optimum maximum lift coefficient and the corresponding reduction in take-off distance due to the trailing edge flap, assuming $C_{L\,max}$ without flaps is 1.5.

It is interesting to note here that the I.C.A.O. one-engine rate of climb requirements are satisfied at these optimum maximum lift coefficients when the power loadings are less than 12.5 on four-engined aircraft and less than 9.0 on twin-engined aircraft. This result would not necessarily be true for an aircraft with a different drag, but the assumed values were typical.

Wing loading has a negligible effect on the optimum maximum lift coefficient but the wing aspect ratio causes considerable variation because of its effect on the drag of the aircraft during the climb. Take-off distances have been estimated for aircraft with a range of aspect ratios from 6 to 12 at a constant wing loading of 50 lb./sq. ft. and constant power loading of 10 lb./B.H.P. The results are shown in Fig. 20 for all engines operating, one engine out of four failing, and one engine out of two failing. On twin-engined aircraft it appears essential to have

an aspect ratio of at least 10, giving an optimum maximum lift coefficient of just over 2.0. On a four-engined aircraft considerable reductions in take-off distances are possible by increasing the aspect ratio up to 12 when the optimum lift coefficient is about 3.0. With all engines operating there is little to be gained by increasing the aspect ratio above 10; the optimum lift coefficient in this case being about 3.5.

On the basis of these estimates it appears that a maximum lift coefficient of from 2.5 to 3.0 in the take-off condition is desirable on four-engined aircraft. It is stressed again that with moderate power loadings full advantage of high lift coefficients can be taken only if the drag on the climb is kept low by using high aspect ratios and high lift devices which are inexpensive in drag. If trailing edge flaps are employed to produce the lift, the flaps should certainly be slotted and should be giving rather less than their maximum lift increment. This is advisable because, as already mentioned, the drag increases rapidly at large deflections; for normal slotted and Fowler flaps the deflection should not exceed 30°. In addition, it is important to keep the flap span as large as possible. It has been mentioned in Section 2.2.3 that this tends to reduce the interference drag, but it also reduces the induced drag which is so important at high lift coefficients.

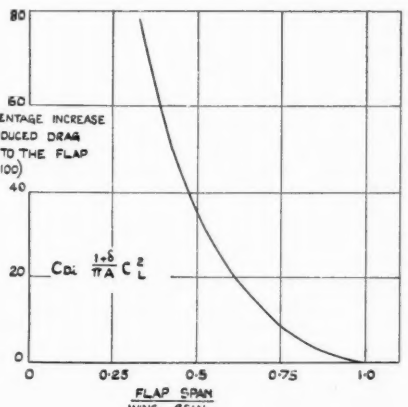

Fig. 21.

Percentage increase in induced drag due to the flap in terms of the flap span ratio for a typical aircraft at climbing incidence.

It can be shown theoretically that the induced drag is a minimum when the spanwise lift distribution is elliptical. With a taper ratio of 2:1 the lift distribution is sufficiently close to the ideal to produce little more than minimum induced drag, but when part span flaps are deflected the lift distribution is distorted and the induced drag may be as much as 40 per cent. more than the theoretical minimum. As the span of the flaps is increased, assuming a constant flap chord ratio, the distortion becomes less until with full span flaps the distribution is the same as with flaps retracted. If the induced drag coefficient (C_{Di}) is expressed as

$$C_{Di} = \frac{1+\delta}{\pi A} C_L^2$$

then the term δ represents the increase in induced drag compared with the theoretical minimum. The percentage increase in induced drag ($\delta \times 100$) is plotted in Fig. 21 as a function of the flap span for a flap giving an increment in lift coefficient of 1.0, at the climbing incidence, on a wing with an aspect ratio of approximately 12. For this typical aircraft, using a maximum lift coefficient of 2.5 for take-off, the induced drag on the climb will be about four times the profile drag of the flap; thus a 10 per cent. reduction in induced drag is equivalent to a 40 per cent. reduction in profile drag. In other words, increasing the flap span from 50 per cent. to 63 per cent. would give a result equivalent to halving the profile drag of the flap.

As the power loading is reduced, drag becomes less important and it is advantageous to use high lift devices, even if the associated drag is rather large. At a power loading of 6 lb./B.H.P. and a wing loading of 50 lb/sq. ft. a 10 per cent. change in drag gives only about one per cent. change in the take-off distance. These conditions are most likely to exist with military aircraft and in the extreme case of the interceptor fighter it is quite probable that the best flap setting for take-off will be full flap, as used for landing.

3.2. During the Approach to Landing

The landing approach is assumed to be the part of the landing manœuvre in which the aircraft reduces height from the circuit height down to 50 ft. The trailing edge flaps, or other high lift devices, will be at least partially extended before the aircraft begins

to lose height and will be fully extended by the end of the approach.

During this stage the pilot must be able to vary his rate of descent to correct for errors in judgment and the effect of wind gradients. The ease with which such corrections can be made will depend to some extent on the maximum gliding angle at the approach speed. This in turn depends chiefly on the drag of the aircraft, and one of the uses of high lift devices is to provide extra drag for this purpose. It is not usually necessary to consider this requirement for drag when designing the high lift device since the inevitable induced drag should be adequate.

To enable the pilot to make accurate approaches it is necessary to provide him with a good field of view, forward and downwards. The standard of view can always be improved by reducing the incidence used on the approach and trailing edge flaps form a convenient method of achieving this. The incidence on the approach will be determined by the stalling incidence and the margin in speed above stalling speed required for safety. Assuming that the approach speed is 30 per cent. above the stalling speed and assuming that the flaps do not alter the stalling incidence, then it can be shown that the change in incidence ($\Delta\alpha$) due to deflecting the flaps at the approach speed is given by:—

$$\Delta\alpha = \frac{0.4\Delta C_L}{a}$$

where a = slope of the lift curve.

Thus for a lift coefficient increment of 1.0 the reduction in incidence would be about 5° and this could well cause a marked improvement in view.

This improvement in view will only be obtained with high lift devices which produce an increase in lift at constant incidence, such as trailing edge flaps. With a leading edge slat the view would be made worse, unless it were used in conjunction with high lift flaps or a variable incidence wing.

In some special cases it appears that means for rapidly changing lift coefficient without altering incidence can provide the pilot with a useful control for making rapid adjustments to his approach. The device would work in much the same way as the lift spoilers sometimes used on gliders. A control of this sort has been suggested for jet-propelled fighters for use during landings on aircraft carriers and the results of some flight tests have been promising. In this case the changes in lift coefficient have been obtained by rapidly altering the deflection of a trailing edge flap. It has also been suggested that a similar type of control might be of use in helping the pilot to remain "in the beam" during instrument approaches.

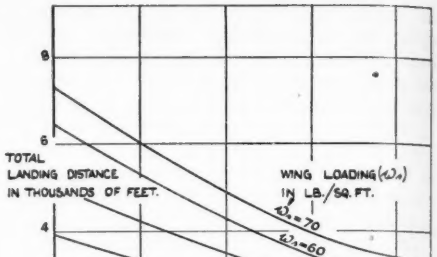

Fig. 22.

Variation of total landing distance with maximum lift coefficient for a range of wing loadings.

3.3. During Landing

In the past the landing distance, measured from a height of 50 ft. to the point where the aircraft stops, has usually been shorter than the take-off distance. There has been a tendency, therefore, in recent years to concentrate on reducing the take-off, while the landing has been somewhat neglected. In the future it is probable that the landing distance will become critical because of increased wing loadings and severe airworthiness requirements. As in the case of take-off, high lift devices will continue to be essential in order to operate aircraft efficiently from existing aerodromes.

The landing distance from a height of 50 ft. to rest has been estimated for the same range of aircraft considered in the last Section. In each case it was assumed that sufficient engine is used on the approach to reduce the gliding angle to 3° and the maximum deceleration on the ground was taken as $0.25g$. The variation of drag coefficient with $C_{L\,max}$ was the same as in the take-off estimates and is given in the

Appendix. The overall landing distance is plotted against maximum lift coefficient, without power, in Fig. 22. Once again it must be emphasised that these curves are only intended to indicate the type of variation to be expected. When a particular aircraft is being considered it is essential to make detailed calculations taking into account, for example, the geometry of the aircraft and type of brakes employed. The curves show that increasing maximum lift continues to give reductions in the landing distance up to a $C_{L\,max}$ of 3.5, irrespective of the wing loading. Increasing the maximum lift coefficient from 1.5 up to 3.5 reduces the landing distance by 54 per cent. at a wing loading of 70 lb./sq. ft. and by 34 per cent. at a wing loading of 20 lb./sq. ft.

The I.C.A.O. requirements specify a minimum rate of climb with all engines operating and the flaps in the landing position. With the higher power loadings this will limit the maximum lift coefficients which can be used. At power loadings below 12 lb./B.H.P. the required rate of climb can be attained with maximum lift coefficients greater than 3.5 for the particular aircraft considered, but at a power loading of 14 lb./B.H.P. the lift coefficient is limited to 2.75. At a power loading of 16 lb./B.H.P.

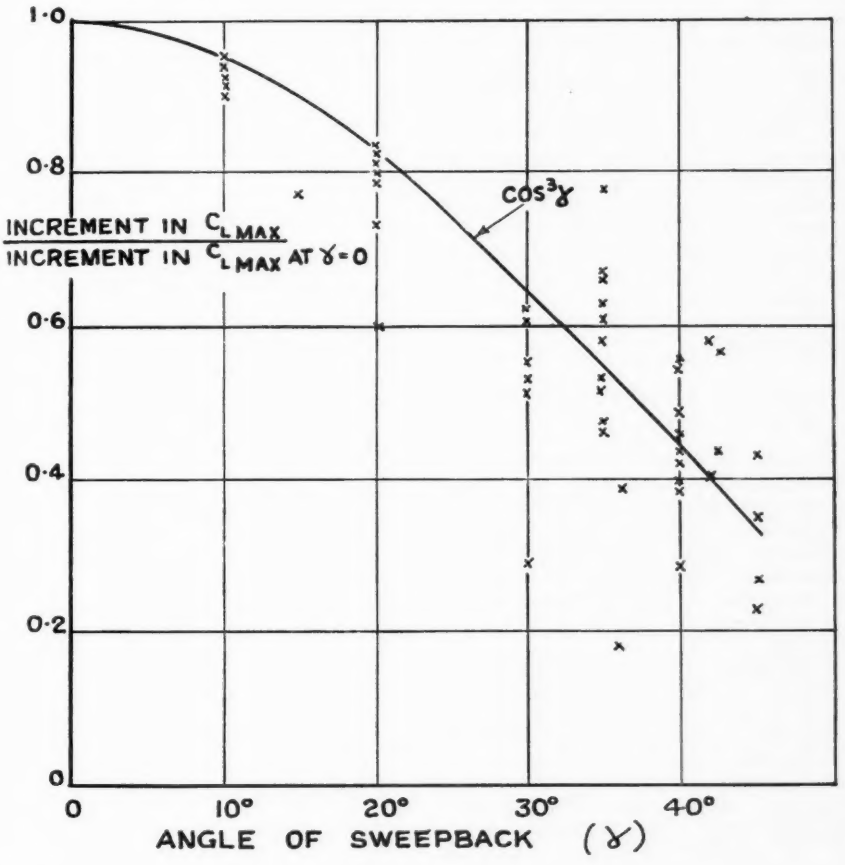

Fig. 23.

Effect of sweepback on increment in maximum lift coefficient due to trailing edge flaps.

it is impossible to meet the requirements at any lift coefficient. These results only apply to aircraft with drag coefficients similar to the assumed values.

Lift devices reduce the landing distance by reducing the speed at touch down and thus reduce the energy which must be dissipated by the brakes and tyres. While reduction in touch-down speed is desirable, care must be taken to ensure that the high lift devices do not reduce the effectiveness of the brakes at the same time. For example, if the maximum lift coefficient of a given aircraft is increased by fitting larger flaps, then the lift coefficient while running along the ground will be increased by a similar amount. This will reduce the load on the wheels and therefore restrict the deceleration which can be obtained by the brakes. In certain cases, particularly when high touch-down speeds are employed, this effect can be important and there will be a case for rapidly reducing the lift coefficient directly the aircraft touches down. The tricycle undercarriage arranged so that the aircraft touches down with the nose wheel well clear of the ground, provides an excellent method of reducing lift by nosing over on to all three wheels. With certain aircraft it may be advisable to move the landing flaps into a position giving drag with reduced lift, or even go to the extreme of providing a negative lift to increase the braking power.

4. HIGH LIFT DEVICES FOR SWEPT-BACK WINGS

It is now common knowledge that the peculiar problems experienced in the transonic speed range make it desirable to use wings with swept-back plan forms. The next generation of military aircraft, therefore, may be expected to have swept-back wings and it is important to consider how this will affect methods of obtaining high lift coefficients.

At the present time the amount of data available on high lift devices with swept-back wings is limited compared with the data on unswept wings. Nearly all the evidence has been obtained from the results of wind tunnel tests and the Reynolds numbers tend to be low. There have been very few systematic tests. The conclusions drawn must be regarded as tentative and the accuracy of any performance predictions is likely to be poor, but some general trends are clearly visible.

(*i*) *Trailing edge flaps*

The increment in lift coefficient which can be obtained by a trailing edge flap is reduced as the angle of sweep increases, until at very large angles of sweepback (60°) there may be no increase in maximum lift at all. It has been suggested[1] that for a given flap the ratio of the increment in maximum lift coefficient with sweep, to the increment in maximum lift coefficient without sweep, is given very roughly by:—

$$\frac{\Delta C_{L\,max}}{\Delta C_{L\,max}\ \text{at}\ \gamma=0} = \cos^3\gamma$$

where γ = the angle of sweepback.

This relationship is plotted in Fig. 23 with the results of a number of wind tunnel tests which show a large amount of scatter. This scatter is not surprising since the measurement of maximum lift coefficient is always sensitive to variations in the test conditions and taper ratio, aspect ratio and Reynolds number will affect $C_{L\,max}$ as well as the angle of sweepback, but no consistent variations were apparent. The curve suggests that with 45° of sweepback the increase in maximum lift coefficient due to a flap will only be about one-third of the increment on an unswept wing.

Tests with simple split flaps show that the stalling incidence is always reduced by at least two or three degrees when the flaps are deflected and this partly explains the small increase in maximum lift coefficient. Some of this loss can be regained by moving the hinge point of the split flap back to the trailing edge. It has been mentioned in Section 2.2.1 that increasing the effective chord by this means gives an increase in maximum lift coefficient of about 20 per cent. on an unswept wing. With large angles of sweep (42° and 60°) the increase amounts to about 50 per cent. In one particular case with a flap chord of $0.184\bar{c}$ extending half the span of a wing with 42° sweepback, the increment in maximum lift coefficient due to the flap was increased from 0.2 to 0.3 by moving the flap hinge point from $0.816\bar{c}$ to $1.0\bar{c}$. This suggests that the best type of slotted flap for a swept wing would probably be a Fowler, which also includes a large amount of rearward extension.

(*ii*) *Leading edge slats and flaps*

Probably the most troublesome characteristic of the swept-back wing is the stalling of the tip sections at a considerably lower

incidence than the root sections. This causes serious longitudinal stability problems and it also causes large reductions in maximum lift. Leading edge slats are effective in delaying this stall and there is a resulting increase in maximum lift coefficient. As an alternative to a leading edge slat, the leading edge flap appears to be equally effective, both in delaying the stall and increasing the maximum lift. To obtain appreciable increases in $C_{L\,max}$ by a slat on an unswept wing it is necessary to make the slat cover the entire wing span, but with a 40° swept wing a 50 per cent. span leading edge flap (or slat) can increase the stalling incidence by 5° or 6°, causing a corresponding increase in maximum lift coefficient. Increasing the span of the leading edge flap gives a progressive increase in maximum lift coefficient; a full span flap giving a $\Delta C_{L\,max}$ of 0.5 on wings with about 40° of sweepback.

(iii) Pitching moments

With a swept-back wing some slight relief on the pitching moments due to a flap can be obtained by limiting the span of the flap to approximately half the wing span. By concentrating the flap on the inboard half of the wing, the centre of pressure of the increased loading due to the flap is kept farther forward relative to the aircraft centre of gravity than is possible on an unswept wing. With 40° sweepback and an aspect ratio of 3.5 the increment in pitching moment due to the flap will be 60 per cent. to 70 per cent. of the value for an unswept wing, provided that the flap is only half span. If the flap is full span, the increment will probably be about the same as that obtained on a wing without sweepback.

If further reduction in pitching moment is essential then split flaps can be used with their hinge point placed well forward of the trailing edge. By limiting the flaps to half span and adjusting the hinge position, it is possible to achieve zero pitching moment change, but the maximum lift increment will be seriously limited.

It is most necessary to reduce the pitching moment change when a tailless design is being considered, otherwise there will be a disastrous loss in lift due to trimming. This is because the loss in lift is inversely proportional to the distance of the trimming device from the centre of gravity, a dimension which is inevitably small on any tailless design. When a tail is fitted the pitching moment changes are less serious and much larger lift coefficients become possible. With swept-back wings the tail volumes are likely to be quite small and, in fact, will be little more than trimming devices. This will make it more difficult to balance out the large pitching moment changes associated with Fowler flaps, as shown in Section 2.2.4. There will also be a greater loss in lift coefficient increment, due to trimming, than with a similar flap on an unswept wing.

5. CONCLUSIONS

The more important conclusions reached in this review of high lift devices can be summarised as follows:—

(*i*) Maximum lift coefficients of 2.8 are quite practicable with a conventional aircraft layout using conventional controls.

(*ii*) Airworthiness requirements make it important to keep the flap drag down to a minimum and the best results are obtained with single slotted and Fowler flaps. Increasing the flap span is effective in reducing the overall drag particularly at high lift coefficients.

(*iii*) With large tail volumes the trim changes due to flaps are least when the pitching moment due to the flap is large.

(*iv*) Ground effect on trim is unlikely to be serious if high lift flaps are only used with large tail volumes.

(*v*) Loss in lift due to trimming can be kept down by using large tail volumes.

(*vi*) Obtaining high lift coefficients by boundary layer control applied to the flow over a trailing edge flap is unlikely to be practicable, because of the large quantities of air which must be ducted through the wing.

(*vii*) For take-off with a power loading of 10 lb./B.H.P. the optimum $C_{L\,max}$ appears to be about 2.8 for four-engined aircraft and about 2.0 for twin-engined aircraft. Use of flaps to give these optimum lift coefficients reduces the take-off distance by more than 35 per cent.

(*viii*) For landing with power loadings up to 12 lb./B.H.P. it is worth while using lift coefficients up to at least 3.5.

(*ix*) With swept-back wings the lift increments due to flaps are reduced and it

is more difficult to maintain trim without serious loss in lift. A trimming tailplane appears to be essential if the required maximum lift coefficient is greater than about 1.2.

These conclusions lead to the suggestion that many British aircraft are not making the best possible use of high lift devices. This applies particularly to four-engined aircraft and is disappointing in view of the very promising start made by this country in the early days.

6. ACKNOWLEDGMENTS

The author is indebted to the Chief Scientist for permission to present this paper; the views expressed are his own and do not necessarily represent the views of the Ministry of Supply. He wishes to thank his colleagues at the Royal Aircraft Establishment for their help in the preparation of this paper and, in particular, he would like to thank Mr. R. Maine and Mrs. V. Hawes who were responsible for the majority of the calculations.

APPENDIX I

In calculating the take-off and landing distances the following assumptions have been made:—

(*i*) The climbing speed, $V_A = 1.2\,V_S$ where V_S = stalling speed, with the appropriate high lift devices but with zero engine power.

(*ii*) The coefficient of friction, with rubber tyres rolling on a concrete runway, was taken as 0.03.

(*iii*) The lift coefficient during the ground run, C_{L_G}, was taken as

$$C_{L_G} = (C_{L\,max}/1.44) - 0.5.$$

(*iv*) The profile drag coefficient of the aircraft with undercarriage extended and cooling gills open was taken as 0.045.

(*v*) The increase in profile drag coefficient due to a windmilling propeller was taken as 0.01.

(*vi*) The presence of the ground was assumed to decrease the induced drag to 60 per cent. of the free flight value when the aircraft was on the ground.

(*vii*) When one engine was assumed to fail during take-off this was assumed to occur instantaneously, directly the speed reached 1.2 V_S.

(*viii*) The touch-down speed during landing was taken as 1.3 V_S.

(*ix*) The variations of drag coefficients with the maximum lift coefficient are given in Table IV.

TABLE IV

C_L max.	1.5	2.0	2.5	3.0	3.5
Flap profile drag coefficient	0	0.006	0.020	0.045	0.071
Total drag coefficient on the ground	0.051	0.066	0.094	0.138	0.206
Total drag coefficient during climb	0.085	0.121	0.175	0.252	0.361

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DISCUSSION

W. G. A. Perring (Director Royal Aircraft Establishment, *Fellow*): The increment of lift associated with the various forms of flap, the increment of drag incurred and the associated pitching moment, were now fairly well established and the problem facing the designer was how to apply this information in the best possible way. The lecturer had shown some ways of employing the lift obtainable with flaps to deal specially with the landing and take-off problems. In general the take-off problem, for conventional aircraft, usually presented the greatest difficulty, since apart from the relief due to the lighter load at landing there was the need to cover the engine-cut condition during take-off, which greatly increased the take-off distance.

In general when considering take-off distance and the associated climb to 50 ft., optimum conditions in the case of aircraft of conventional design were reached with lift coefficients of about 2.0 for twin-engined aircraft and 3.0 for four-engined aircraft; lift coefficients that could be readily achieved. With leading edge slats and the Fowler type of flaps it was quite easy to obtain a lift of 3, and it was well within the power of the aerodynamicist to provide 3.5 if it were needed.

Although it was unnecessary to employ those extremely high lifts for take-off the lecturer had shown it was still profitable to go on using lift coefficients up to 3.5 for landing and it would be useful to know whether such high lift coefficients could be employed in the landing condition without introducing the extra complication of a variable incidence wing.

Admittedly the problem was one of geometry but his impression was that the incidence changes associated with lifts greater than 2.8 to 3 necessitated variable incidence wings being used.

Large tail volumes had usually been advocated on the grounds of the increased stability they provided, and the two additional reasons put forward by the lecturer gave added strength to the contention that it was desirable to keep tail volumes large.

It might seem that designers had only to exploit the high lift which research on flaps and slots had shown to be possible, a rather happy state of affairs, but unfortunately, as the lecturer had indicated, the introduction of sweepback and the need to use thin wings had again, in certain classes of aircraft, made the high lift problem acute. The employment of a thin wing reduced considerably the possibility of obtaining a high lift, and sweepback added to the difficulties, while the use of a small aspect ratio so lowered the general slope of the lift curve that it was unlikely full use could be made of high lift for landing even if it were obtainable. Future high speed aircraft, therefore, would have to face a difficult landing condition unless some way could be found of increasing and exploiting high lift in the more unconventional designs foreshadowed by present trends. With such aircraft the landing might well prove a more difficult problem than take-off, since assisted take-off could partially solve the take-off problem and might become an essential design feature. There was some possibility that boundary layer suction could be applied to improve the lift coefficient and the stalling qualities in these extreme cases. What did the lecturer think of such a possibility?

There was a need to develop better forms of braking and brakes that could be used to maximum capacity throughout the whole of the landing run. Some automatic device was wanted which would be capable of applying the full braking force up to the limit fixed by the skidding of the wheels on the runway.

J. F. Foss (Airspeed Limited, *Assoc. Fellow*): In Section 2.2.4(*i*) the author referred to the effect of power upon the change of trim arising from flaps and admitted that the effect could be large and also difficult to predict, but he thought the author was wrong in suggesting an adjustable tailplane as the solution.

The time when change of trim due to change of power was critical was in a balked landing and clearly, unless the adjustment to the tail setting was geared to the throttle, and he did not think that was what the author intended, a tail setting geared to the flap angle would have no direct bearing on the matter.

He was glad the author had mentioned the adverse effect which flaps could have on the maximum amount of wheel braking which could be used, and it followed that the nose-wheel undercarriage was a natural corollary to the high lift flap. In that

connection the current civil airworthiness requirements were, in his view, unduly restrictive in that although the aircraft had to approach at 1.3 times the stalling speed, the flap angle might not be altered until the speed had dropped 40 per cent., *i.e.* to 0.9 times V_{80}. That was intended to rule out too much dependence upon the skill of the demonstrating pilot, but at the same time he considered the more equitable rule would be that the flap angle should not be changed until the speed had dropped to 0.9 times touch-down speed, where the latter was the forward speed at which the main wheels touched the ground in the scheduled landing distance with the appropriate number of engines in operation. The present ruling would usually only be restrictive in the " all-engines-operative " condition, but there might arise a case with low power loading in which it also restricted the one-engine-inoperative landing, because then they might be able to meet the climb requirements with flaps fully down.

The use of a small wing incidence when a nose-wheel aircraft was standing on the ground was a contribution towards greater braking, or at least greater freedom from skidding and, subject only to the fact that it required a finite time—during which the aircraft covered a finite distance—for the pilot to rock the aeroplane about its main wheels both on landing and take-off, he thought the adoption of ground attitudes at which the lift coefficient with flaps in the take-off setting did not exceed about 0.2 might be desirable in certain cases. That reduced the induced drag during the unstick run and also increased the weight on the wheels for braking without skidding, both in the accelerate-stop case and in the normal landing.

It was sometimes important from the performance point of view to design to a high value of take-off C_L even if it did not make much difference to the screen distance, because of the requirement that the aircraft must be able to clear 50 ft. *or stop* within the length of the runway, following failure of one engine at the critical point. True, the critical point would be chosen as the point at which both those distances were the same, but any reduction in critical speed because of the accelerate and stop requirements only worsened the climb-away distance.

There was one aspect of the use of high lift devices for take-off on a high powered four-engined propeller-driven design which the author had not mentioned, although he was probably well enough aware of it, and which might become critical if the span loading were high and the power loading low, namely the roll due to the loss of slipstream over a highly flapped out-board portion of the wing. (That would have a tendency to force designers to use high aspect ratio wings to the general improvement of their take-off and climb performance and so would be a good thing in the long run!)

The point about roll following engine failure did not apply in anything like the same degree with jet-driven aircraft as with propeller types. That was just as well because it seemed to him that there would be more need to go for large flaps for take-off with jets because the climb portion of the take-off run would be relatively steeper and the accelerate and stop problem would be great, especially without reversible or at least windmilling propellers.

On the subject of the " far back C.G. cum large tail volume " policy, while aerodynamicists must have known, as he did himself, that two of the merits of this were (i) a minimum loss and, eventually, a gain in $C_{L\,max}$ due to trimming; and that in turn meant a minimum C_{Di} with flaps down, and (*ii*) a minimum change in elevator angle to trim with change of flap setting, that policy had very seldom been adopted—he could recall only the experimental Lysander with a tailplane 43 per cent. of the size of the main plane, which was quite satisfactory at a C.G. of 58 per cent. of the chord.

One reason was because the aerodynamicist was usually regarded as a bit of a " Jonah " when he was, as sometimes did happen, in the position of asking for a slightly larger tail volume to give what he thought was a reasonable stability margin and his design colleagues were contriving their best to push the C.G. forward, and so resented any " unnecessary " weight in the tail.

Another and better reason was that it was not necessary to design for minimum change in elevator angle with change of flap setting.

It had to be remembered that what the pilot would *not accept* was a large change in stick *force* to trim, but he usually did not mind a change in stick *position*. It was possible to achieve a small change in stick force to trim by designing for a downward change in elevator angle to trim and using

the change of downwash to balance out the control force.

That meant that the last ounce of stability could not be got out of the tail by the use of a positive b_1 (not that positive b_1 on the elevator was an unmixed blessing!) but it did not follow that the tail volume was unnecessarily large because the elevator then had enough angular movement to enable the aircraft to be landed, whereas it would have had to be bigger if they did not design for the downward change in elevator angle to trim out the change in moments arising from change of flap setting.

He agreed they should not generalise on the matter because one formula fitted a type of aircraft designed for one particular duty, whereas an altogether different type of aircraft was naturally better for some other duty, and he thought there was a case for serious consideration being given to the "far back C.G. cum large tail volume" policy for high lift transport aircraft, although the point he had made earlier about change of trim with power would still have to be considered. This might mean that the "large tail volume" policy could only be adopted on aircraft with the thrust line above the C.G. (*e.g.* a high wing monoplane) unless power-assistance were used to overcome heavy elevator control forces, which was something they would like to avoid.

After all if a large tail volume were obtained by a good tail arm, at least the space could be used to house some of the payload and the parasitic portion of the tail volume was then kept to a minimum.

The author had not mentioned that the reason for the loss of effectiveness of flaps on swept-back wings was that the flow had a noteworthy spanwise component when the angle of sweepback of the flap was equal to the angle of sweepback on the wing. That was surely a major reason for the ineffectiveness and it would be of interest to see whether the effectiveness of flaps (and of ailerons) on swept-back wings could be increased by so arranging the hinge line that the sweepback of the flap was not so great as that of the wing.

If large sweepback were used to obtain the last ounce of speed there would be a desire to make the design into a tailless one and then little gain in lift could be obtained by the use of flaps, since the nose-down moment due to the flaps had to be balanced by a nose-up moment due to the elevons, with a consequent reduced gain in $C_{L\,max}$, and in the limit, presumably tip instability due to premature stalling.

He genuinely thought the paper would be of great advantage to students, but he criticised the fact that Mr. Duddy had not mentioned induced drag when discussing the choice of flap, because that was possibly misleading.

A point he had noted during the paper was the emphasis on the slotted flap interference. He imagined that the Royal Aircraft Establishment had tried what was obvious as a means of reducing it, but he wondered if they had really tried their best! It was bound to be important to a civil aeroplane. And again end-plates had been tried to get a higher maximum lift increment out of the wing, and possibly some improvement in induced drag. He wondered if they had shown any improvement.

One of the big snags of high lift flaps was the tremendous amount of distance the pilot had to use to flatten-out and he wondered if the curves in Fig. 9 had taken that fact into consideration.

Another point with regard to getting the optimum lift/drag from flaps for take-off was the urge to increase flap span, and so reduce the induced drag, but lateral control in the form of conventional ailerons put a definite limit to flap span. Had the progress with spoilers been such that the author could really recommend them as a practicable and satisfactory arrangement permitting full span flaps to be used?

A. N. Clifton (Vickers-Armstrongs (Supermarine), *Fellow*): Portsmouth was most suitable for the lecture because of its close association with the Navy. Naval aircraft were required to land on deck and in short distances and to fold up more or less neatly into the smallest dimensions; if anyone needed high lift it was the Navy. At Supermarines they had had some experience of high lift in the form of full span slats combined with slotted flaps. They had built two aeroplanes using those features and they had reached the conclusion that variable incidence of the main plane was desirable in order to reduce the body incidence at maximum lift and also to provide tail trimming. Mr. Perring appeared to take the view that variable incidence was a thing to be avoided at all costs. He presumed he was thinking of it from the engineering aspect and he felt that from that viewpoint the same could be

said of all high lift devices. From the engineering angle they were all, or nearly all, unpleasant. The higher the lift, generally speaking, the more unpleasant. Variable incidence was by no means the worst, in his experience. Compared with some of the mechanisms they were forced into when they wanted to hang a flap on the trailing edge of a thin wing, for example, the variable incidence wing seemed comparatively simple.

Of the two aeroplanes to which he had referred, the first was a bomber-reconnaisance type and achieved a maximum lift coefficient of 2.6 engine-off. That was not, perhaps, particularly high. The second, an amphibian, was at present undergoing trials and it appeared likely to achieve its design maximum lift coefficient of 3.5, engine-off. That lift coefficient would be considerably exceeded, engine-on. Bearing in mind that this was an amphibian, the maximum lift came in useful when landing in a rough sea, a point which was not mentioned by Mr. Duddy in favour of high lift devices.

Mr. Perring had summarised the sort of problems that arose with the high speed type of aeroplane, assuming they had wings with considerable sweepback. There again the problems were not only aerodynamic, but the engineering part also became difficult with such aeroplanes. He had rather hoped for a little more encouragement from the lecturer as to how they might get a higher maximum lift on thin swept-back wings.

Mr. Duddy had dealt very comprehensively with the aerodynamic aspects of the problem of high lift, and in the time available he could not go into such matters as weight and engineering. There was probably scope for a paper from someone on the subject of the weight and engineering aspects of high lift devices.

Had Mr. Duddy done sums which satisfied him that it was better to put greater area on the tailplane in order to get a higher maximum lift coefficient on the main plane, rather than put the extra area on the main plane and be satisfied with a lower lift coefficient?

D. C. Wood (A. V. Roe and Co. Ltd.): The lecturer had mentioned interference effects on the lift increments of split-type flaps. The experience his company had on the York with its high wing arrangement indicated that considerable wing-fuselage interference on the lift increments produced by the split flaps was present. The interference was such that the split flaps had to be assumed to be continuous across the fuselage.

The comparison between the measured lift increments and those calculated by the Royal Aeronautical Society's Aerodynamic Data Sheets was as followed:—

	Lift increment ΔC_L Flaps 25°	Flaps 56°
Measured	0.49	0.71
(*a*) Assuming cut-out at fuselage	0.33	0.54
(*b*) Assuming no cut-out at fuselage	0.41	0.66

The flaps on the York were of the split type, with the flap area as a percentage of the flapped wing area of 21.5 per cent. The flapped wing area as a percentage of the gross wing area was 50 per cent., assuming a cut-out in the flap span at the fuselage, the percentage was, however, increased to 59 per cent., if the split flap were assumed to be continuous across the fuselage.

Those results confirmed some of the points which the lecturer had mentioned. It was to be regretted, however, that they had no evidence of the measured increments of drag coefficient, so as to show the extent which wing fuselage interference had on the drag increments of the split-type flaps on the York.

The author had carefully avoided the effects of power on trim, when high lift devices were used. On high powered multi-engined aircraft the effect of power during a balked landing, with the high lift devices in the landing position, might require the elevator and the elevator angular ranges to be larger than normal. Could the lecturer give any helpful advice on this matter?

Other speakers had spoken about large tailplane volumes; were they really necessary? Could they get round the difficulties by having the C.G. range farther forward? A large tailplane volume could be a disadvantage, especially when every ounce of payload was needed, then the tail surfaces should be kept to a minimum.

J. F. Foss (Airspeed Limited, *Assoc. Fellow*): His experience had been that the loss of lift was small compared with the loss they would theoretically get if there were a gap without any body filling it. It was such that they had to estimate that most of the gap at the nacelles was filled up and some of the gap at the body also filled up in order

to predict the measured result from A. D. Young's generalised curves.

N. E. Rowe (British European Airways, *Fellow*): It seemed to him that the test of all high lift devices was how they behaved in the air. It was not much good having a very high lift coefficient if the flying qualities were such that the pilot was not prepared to fly at the low speeds that seemed to be possible on paper. The inter-action of the high lift devices and the stability and control of the aircraft were extremely important. A previous speaker had mentioned the question of lateral control, especially the lateral control when taking the effect of the flap to its limit. The lecturer had said various things could be done to get over it, *e.g.* if they wanted a high span flap all they had to do was to shorten the aileron, but this raised many incidental problems. They could balance ailerons and forestall flutter and so on, but unless the controls and the stability remained such that the pilot had full confidence to fly the machine at low speeds, then some of the value of the high lift might be lost. What did the lecturer think?

Another point was how far the nature of the stall was affected by high lift devices. Was the stability likely to deteriorate rapidly as they reached the lowest speeds? If that were so then pilots would not be prepared to use the full value of the high lift devices in general operations.

Mr. Clifton had mentioned some of the points he had had in mind. One was the engineering and there was the general point there that he thought the engineering was difficult. There might be a need for a compromise that, rather than go to the limit or even to the order of $C_{L\,max}$ of 2.5 or 3 and get a great deal of complexity in the engineering, it would be far better to have a somewhat lower coefficient with simpler engineering that really worked.

High lift was inextricably mixed up with weight. It was clear from the graphs shown how great a part wing span played in it and span could be obtained only with a careful balance of weight. There was the weight of the flap itself and the extra controls required. The question of payload bulked largely in this matter, so that while the lecturer was right in avoiding going off on those structural weight questions, they needed another paper on that aspect because the whole problem related to overall economy had to be taken, not only the high lift coefficient that could be obtained aerodynamically. How far the very high lift coefficients were worth having in terms of weight increase, added complexities of control, and so on, remained to be seen.

The lecturer had mentioned the increase in drag affecting the take-off and the amount of flap that could be used. He wondered if in his calculations he had included the increase of drag due to the slip stream over the flaps!

A. G. Shove (Airspeed Limited): A vast amount of weight data had been supplied by firms during the past decade, both in type records and "2492's," and the R.A.E. alone had this and all the additional data necessary to prepare such analyses.

He had prepared plottings of flap weight per sq. ft. of flap area against flap design speed, but scatter was considerable and the plotting was of doubtful value for estimating purposes and useless for comparing different types of flaps. It had been suggested that a plotting of flap plus mechanism weight per sq. ft. of flap area against ΔC_L would give better results, but he was having considerable difficulty in getting the necessary data together and did not have any real hope of being able to get enough up to date and accurate data to give reliable results.

The lecturer had dealt with the aerodynamic aspects of high lift devices very thoroughly and he thought that the Industry would hold the Royal Aircraft Establishment culpable if it were not followed up with a paper or report on the weight aspects.

M. Salisbury (*Graduate*), *contributed*: There was an error in the advance proof in the equation for $\Delta C_{L\,trim}$ which should read

$$\Delta C_{L\,trim} = \frac{\Delta C_L(h-a) + \Delta C_M}{l/c}$$

where $l =$ tail arm

$c =$ standard mean chord.

He thought it was a little misleading to refer to this term as $\Delta C_{L\,trim}$ since it was strictly the ΔC_L due to the change in tail load on lowering flaps (the aircraft being trimmed before and after the flap operation) and consisted of two parts:

(1) Change in tail load due to change in down wash and incidence; and

(2) Change in tail load required to balance the out-of-trim moment as defined by the lecturer in paragraph 2.2.4 (*i*).

Only (2), he considered was $\Delta C_{L\ trim}$, while (1)+(2) could be termed $(\Delta C_L)_{tail}$.

It was easier to show those points as followed:

Change in pitching moment of wing due to lowering flaps $= qSc\ \{\ \Delta C_L(h-a) + \Delta C_M\ \}$

$(q = \frac{1}{2}\rho V^2,\ S =$ wing area)

To balance this a change in tail load of $\Delta L_T = \dfrac{qSc\ \{\ \Delta C_L(h-a) + \Delta C_M\ \}}{l}$ was required.

Therefore, $(\Delta C_L)_{tail} = \dfrac{\Delta L_T}{qS} = \dfrac{\Delta C_L(h-a) + \Delta C_M}{l/c}$

Also $\Delta L_T = qS_T(a_1\Delta\alpha_T + a_2\Delta\eta)$ where a_1, a_2 had the usual meaning.

$\Delta\alpha_T =$ change in tail incidence

$\Delta\eta =$ change in elevator angle to trim

Then $a_1\Delta\alpha_T$ and $a_2\Delta\eta$ were proportional to (1) and (2) respectively.

For the construction of Fig. 14 a constant degree of stability was assumed. Since, with this condition, $(h-a)$ was dependent on tail volume, $(\Delta C_L)_{tail}$ would, in fact, vary with tail area. Hence two sets of curves should appear on Fig. 14, depending on whether tail arm or tail area were varied.

He appreciated that the effect of tail volume on maximum lift was incidental since, as the lecturer pointed out, tail volume was decided by stability considerations, but it might be of interest to note that with a given tail volume, a large tail area and small tail arm was desirable from a lift aspect with large tail volumes where $(\Delta C_L)_{tail}$ was positive, while with small tail volumes the reverse was true. Weight and other considerations would largely determine the tail arm in practice.

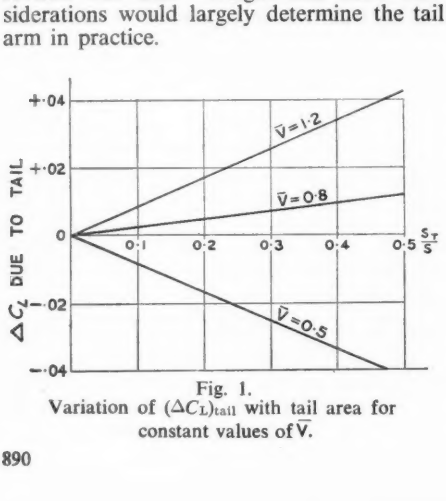

Fig. 1.
Variation of $(\Delta C_L)_{tail}$ with tail area for constant values of $\bar{V}$.

D. J. Lambert (*Graduate*), *contributed*: Mr. Duddy's remarks upon $C_{L\ trim}$ appeared to be rather misleading.

From the point of view of stalling speed and maximum lift coefficient (upon which some stringent rate of climb requirements were based) the important thing was the C_L to trim, based on mainplane area, at the maximum C_L and it could be shown simply that this could be estimated with reasonable accuracy from the following relationship.

Mainplane ΔC_L due to trimming $=$

$$\{\ C_{L\ max}\ (h-a) + C_{M_0} + \Delta C_{M(o)}\ \}\ \frac{c}{l}$$

Where c was the mean wing chord of the mainplane,

l was the tail arm,

other symbols as used by Mr. Duddy.

For a given wing and flap configuration it would be seen that only an increase of tail arm would reduce the magnitude of the effective loss of net lift due to trimming out *a given nose-down moment* and that only on a "fore plane" machine would there be a gain in net lift.

The importance of flap drag could not be overstressed in the case of balked landing and approach conditions. On conventional machines with airscrews it was the drag in the slipstream which caused most of the trouble—losses of airscrew propulsive efficiency of the order of 50 per cent. could be present with double slotted flaps down and undercarriage extended.

With regard to the effect of sweepback on C_L increments due to flaps and on maximum C_L there seemed to be some alleviation of the $\cos^3$ law on low aspect ratio wings of high taper ratio in which the sweep of the flap hinge was much less than that of the 0.25 chord line. There might be room for an extension of the "Boundary layer fence" approach to the slots of slotted flaps on swept-back wings.

R. T. Youngman, *contributed*: In sympathising with Mr. Duddy's disappointment at the lack of use made by British aircraft of high lift devices, they must not lose sight of the fact that the experts at the Royal Aircraft Establishment, acting as they did largely as consultants at advisory design conferences during the initial stages, were at least in part responsible for the present deplorable position. In his own experience he had frequently been given to understand by some of those who were in authority that

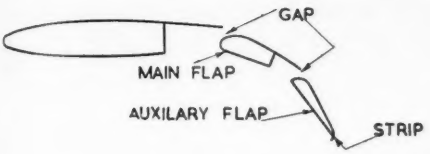

Fig. A.

the problems of take-off and landing could be solved simply by increasing runway lengths.

Lift and drag

In the example shown, Mr. Duddy had chosen for the purposes of comparison a relatively inefficient form of double slotted flap which, because of its small rearward extension, he suggested appealed to the structural engineer. The lecturer also stated that the tests which had been made on double slotted flaps were confined to those which did not make use of large rearward movements. He knew of one case, however, in which tests had been made on a form of double slotted flap such as that shown in Fig. A. This provided a total wing extension of 22.5 per cent. *C*. The results of those tests which were made at aspect ratio 4.0 were fully recorded in Report No. Aero 2158 dated October 1946, and moreover, the results, if converted to the identical conditions of two-dimensional flow, which Mr. Duddy used as the basis for his comparisons, would compare favourably with the double Fowler flap which he suggested offered the best possibilities for the future development of high lift.

He did not know the exact definition of the Fowler flap, but his understanding was that it was projected from the wing on track bars which brought the slot into efficient operation only at the final stages of the movement when not only the lift increment but also the profile drag approached the maximum. Had Mr. Duddy, in expressing his preference for the double Fowler, considered the structural and mechanical engineering problems involved in arranging three aerofoils whose trailing edges coincided, to fit snugly into one another, the means of support and the internal mechanism required to operate the flap, say on a thinnish wing? What was his opinion on the type of double-slotted flap to which he had referred in which the trailing edges of the flaps and wing were staggered and in which the operating links were arranged to provide substantially the optimum configuration for lift and drag during the lowering movement. The configuration shown also admitted of a simple full-span arrangement for normal lateral control by replacement of the auxiliary flap by an aileron over the outer portion of the wing.

Under the heading of Drag, Mr. Duddy favoured the single slot in preference to the double slot because of the high drag of the latter. Did this conclusion also take into account those forms of double slotted flaps which provided a much greater chord extension than the example considered and where the lowering mechanism was designed to provide the optimum slot size for minimum drag appropriate to the flap setting? In this connection, the curve shown in Fig. B showed the optimum gap appropriate to various flap settings which he had obtained in a small wind tunnel for this type of double slotted flap.

Mr. Duddy mentioned that a 10 per cent. split flap fitted to the trailing edge of a Fowler flap resulted in an increase in lift increment of 20 per cent. In the case of the double slotted flap referred to above, he had found that the lift was increased by no less than 8 per cent. by the addition of a strip only 0.01*C* deep to the trailing edge of the auxiliary flap. A number of strips were tested and a curve showing the relation between lift increment and strip depth was shown in Fig. C.

Interference

Mr. Duddy referred under Section 2 to the importance of preventing a breakdown in flow over the root sections. He had found that the disturbance in flow over the wing

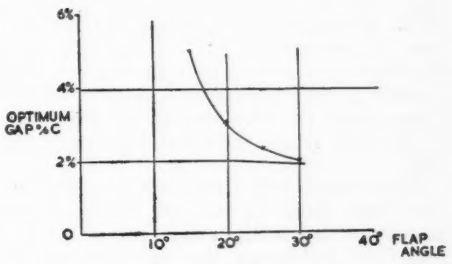

Fig. B.

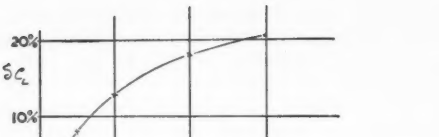

Fig. C.

often resulted from an upwash due to body or nacelle lift. At small angles of attack the interference was generally negligible, but as the aeroplane approached the stall the suction on the upper surface of the body or nacelle increased to such an extent as to create a serious upward diversion of the air stream. In some tests he had made on various body shapes he had found that this increase in incidence could be as much as 10° or more degrees. In particular, this effect was noticeable on low wing aircraft with wide squarish bodies and also to cylindrical bodies with long noses, such as large civil transport types. The stall which started at the wing root spread outward over the wing as the angle of incidence was increased and created an ever-broadening band of turbulent flow over the tail. The turbulence was accentuated by the presence of high lift flaps. He had also found that the fitting of a small slat or guide vane appeared to be effective in restoring the lift to its full value if the guide vane were set in such a position and attitude as to divert the air stream back into its normal path. Such a slat had been found to be effective in cleaning up a section of the wing at least 60 times its own area. The guide vane moreover, seemed to operate satisfactorily irrespective of the degree of expansion at the rear wing body junction and might, therefore, dispense with the need for fillets. It was further significant that such a guide vane appeared to have no effect whatever on the natural stall of the wing and therefore, in contrast with an ordinary slot extending over the inboard portion of the wing, would not itself lead to the dangerous condition in which the tip stalled before the root.

Experiments with fillets indicated that the root stall could be relieved, provided the fillet was sufficiently large and of such a shape as to reduce the incidence by an amount corresponding substantially with the local increase in incidence of the air stream. In severe cases, however, the excessive size of the fillet and local reduction in wing incidence resulted in an increase in profile and induced drag. In addition, the increase in chord and upward deflection of the wing at the trailing edge detracted largely from the optimum performance of high lift flaps which required the nose of the flap to be located under the trailing edge and separated from it by a gap of strictly limited dimensions.

Slipstream and take-off

Mr. Duddy mentioned the usefulness of slipstream lift in take-off but gave no indication of the magnitude of the associated drag and in particular, when the slipstream was associated with high lift flaps. He had made a number of tests at different slipstream diameter-chord ratios and found that the slipstream lift-drag ratio was roughly proportional to the slipstream diameter-chord ratio. In Fig. D he gave mean curve through a number of points obtained on a model representing the double slotted flap shown in Fig. A. If those results were reasonably representative of the actual conditions which obtained in flight, it seemed that the slipstream drag was about half the value of the associated lift for the average diameter airscrew. Subject therefore to correction, he suggested there was a limit to the amount of flap which could be put behind an airscrew in the take-off condition. He had also some evidence to show that slipstream induced drag was unaffected by the proximity of the ground.

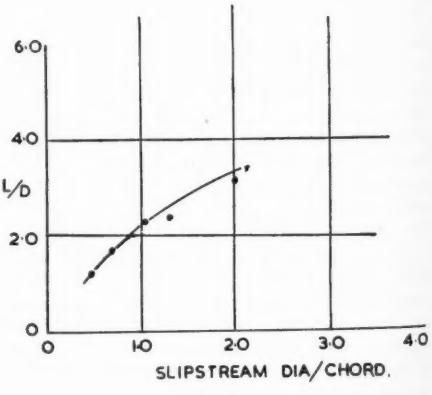

Fig. D.

Referring to Table III, he had always regarded it as most desirable in the take-off condition to provide as great a wing extension as possible, rather than to rely upon large flap deflections for lift increment since by this means, the additional lift was provided at the minimum expense of profile and induced drag. In particular he believed the full span flap which provided a substantial wing extension was eminently suitable for take-off since the wing loading more nearly approached the elliptical form and largely avoided the possible slipstream effect mentioned before. In addition, the extension of the wing tip chord had a favourable effect on the lateral control by delaying tip stall. Was there any official information on slipstream drag and what proportion did it assume in the total drag given by Mr. Duddy in the table in the Appendix.

Mr. Duddy remarked on possible large trim changes in opening up after a balked landing. He had found some evidence to show that this might in part be due to unstalling of the wing root with increasing slipstream velocity. If this were in fact true, a guide vane as described earlier, should have beneficial results. It was hoped to obtain more positive information in the near future.

Lateral control

Mr. Duddy disclosed a simple manner by which a full span flap might be obtained by placing a split flap in front of the aileron. If such a device could be applied to existing types of aircraft, it might go some way towards relieving take-off difficulties without making major alterations. Could Mr. Duddy state whether the lowering of the flap had any adverse effect on the rolling moment, and if so, whether he would consider it satisfactory if applied to large civil aircraft, and particularly twin-engined types when one engine cut out?

Change in trim

Mr. Duddy had defined theoretically an awkward and elusive effect. What pilots called change of trim, was often very different from the theoretical definition, namely, the change in stick force without regard to elevator angle. With the aircraft theoretically in trim, heavy forward or backward loads, depending upon the type of elevator balance employed, might be imposed on the stick when the flaps were lowered.

In several cases with which he had been concerned, it had been found possible by careful adjustment of the elevator balance, automatically to maintain substantially the desired flight path with hands off while the flaps were being lowered.

Boundary layer control

He was glad that Mr. Duddy did not favour the use of boundary layer control as a means of increasing lift for take-off. It seemed incongruous that such a complicated and expensive means of artificially increasing the lift for take-off should ever have been conceived or contemplated when, because of

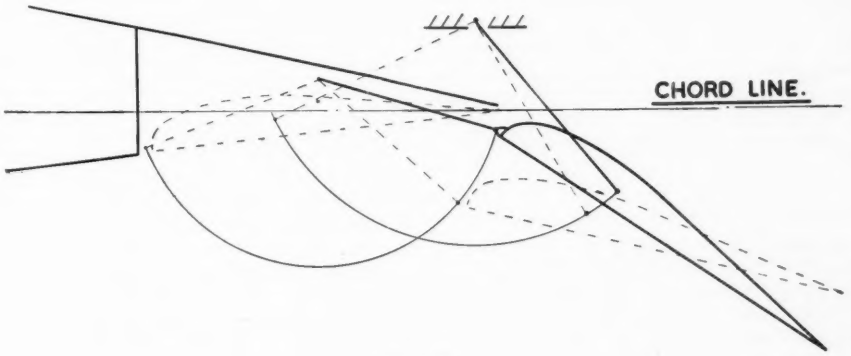

Fig. E.
Link mechanism providing optimum slot size for 15° and 35° flat settings.
Application Fairey Firefly. $C_{L\,max}$ for 30% chord extension 3.3.

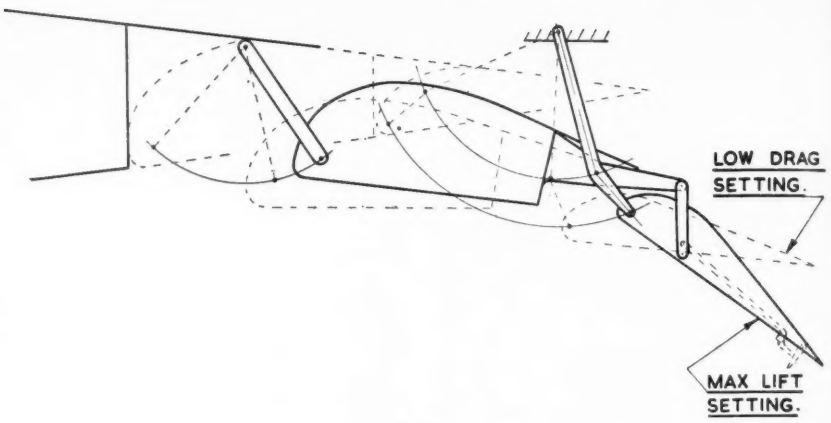

Fig. F.

Diagram of linkage mechanism applied to double slotted flap, providing optimum slot dimensions for take-off and landing. Application M. of S. Exp. High Lift Aeroplane. $C_{L\,max}$ at A.R.$=\infty$ for 25% wing extension 3.75. Estimated $C_{L\,max}$ with added tab, shown dotted, 4.15.

the possibility of mechanical breakdown, slipstream lift possibly derived from the same power unit had never been admitted. If the additional problems of control which would arise with such artificial reduction of flying speed were also considered, he suggested this subject might well be laid to rest until all means of naturally increasing the lift by means of flaps and similar devices had been exhausted.

Manœuvrability

In his list, Mr. Duddy had omitted one important use of flaps to which attention was drawn by the R.A.E. in the early days of the war, namely, the improvement of manœuvrability. With a low drag flap of the form shown in Fig. E it was found possible not only considerably to reduce the radius but also the time to make a banked turn of 360°.

Swept-back wings

He had made some tests on a wing of 45° sweepback and aspect ratio 3.0 equipped with a full span slotted flap which provided a 20 per cent. wing extension at the wing root and reduced to 0 per cent. at the tip. For what his results were worth, he had found that the addition of a strip of 0.05*C* deep to the trailing edge of the flap and extending over the inner quarter span, increased the total lift by 10 per cent. to 15 per cent. without appreciable further change in pitching moment. Reducing the strip to anything less than one quarter span resulted in a nose-up trimming tendency.

In practice the strip might take the form of a tab as shown in Fig. F to act as a lift increasing and/or trimming device or coupled with the elevon to supplement the longidudinal control.

In his summing up, Mr. Duddy referred to the promising start made in this country with high lift devices but made no comment upon more recent developments which formed the logical outcome of one form of high lift device which was developed before the war. The form of flap to which he referred was the link-operated retractable aerofoil flap shown diagramatically in Fig. E. The early wind tunnel tests made at the National Physical Laboratory showed distinct aerodynamic advantages of this method of operation and subsequent tests made by the N.A.C.A. more accurately defined the optimum wing-flap configurations. As indicated in Figs. E, F and G, the link mechanism lent itself easily to the attainment of substantially optimum settings for take-off and landing in a single or multiple slot device.

The first full scale tests were made on a

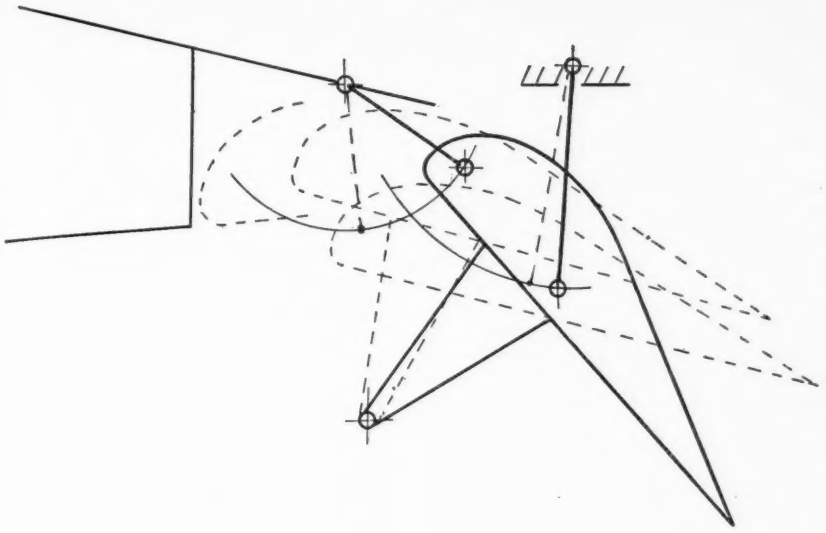

Fig. G.
Diagram showing linkage mechanism, superimposed on conventional offset hinge slotted flap, to give optimum gap for minimum drag and high lift settings.

Fairey Battle with a half span flap of $0.25C_W$ fixed in the high lift position, Fig. E. Flight tests were made with and without the flap extended under the body. In the former case a lift coefficient of 2.3 was attained and there was adequate longitudinal control to make a three-point landing without increase in the standard tail area. With the centre portion removed, there was not only a reduction of about 15 per cent. in maximum lift but also a considerable loss in longitudinal control. This clearly demonstrated the point made by Mr. Duddy that given a suitable lift distribution along the span, high lift flaps were not the criterion of tail volume.

A retractable link-operated flap of this form (Fig. E) was tested on the Fairey P4-34 light bomber and was later embodied on the Firefly Fleet Fighter. It was also incorporated in the design of the Fairey Civil monoplane, the abandonment of which, owing to the war, lost to this country an aeroplane aerodynamically comparable with today's best American types.

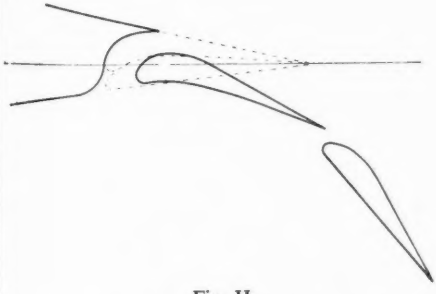

Fig. H.
Diagram of R.A.E. Double Fowler.

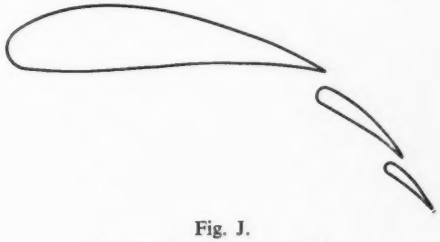

Fig. J.
Junkers Double Slotted Flap.

A discussion on the aerodynamic properties of flaps, he thought, should not be entirely divorced from the associated structural and mechanical problems since an extremely effective wing flap combination might be proposed only to find insuperable difficulties in the way of its practical application. The double-slotted flap (Fig. A), however, lent itself to a simple development of the linkage system shown in Fig. E, as illustrated in Fig. F. This latter showed a section at the wing root. A full span form of this device in which the auxiliary flap was replaced by an aileron over the outboard portion of the wing had been undergoing flight trials at the R.A.E. for the past twelve months. Perhaps Mr. Dully could give some information on the lift and controllability. If this high lift device were applied to a wing of aspect ratio 10 and taper ratio 2-1 with the principal flap extending over the full span and the auxiliary over the inboard 70 per cent. span as assumed in Mr. Duddy's example, he estimated the maximum lift coefficient would be around 3.3 as compared with the highest figure quoted by Mr. Duddy, namely, 2.94 for the slotted flap with fixed slat. The addition of a mechanically-operated tab as shown dotted, should raise the lift coefficient to at least 3.5. In a further development of this form of high lift device, it was anticipated that a lift coefficient approaching 4.0 for an aircraft for the type considered by Mr. Duddy might be reached. It went without saying that lift coefficients of this magnitude might well revolutionise ideas of operating aircraft from carriers which the present speed requirement was making increasingly difficult.

Since making the preceding comments on the R.A.E. double Fowler, it had been ascertained that the device was of the form shown in Fig. H in which the forward unit took the form of a simple slotted flap with the large rearward movement being confined to the auxiliary flap. Aerodynamically, for a given chord extension and camber, there was probably little to choose between the R.A.E. arrangement and the arrangement shown in Fig. A at the setting for maximum lift. The difference, if any, would arise in the low drag setting for take-off due to the different configurations provided by the link and trolley beam methods of operation. As the properties of the double Fowler were known in 1939 it was unfortunate that its use was not promoted by the R.A.E. at the inception, rather than at the approaching termination of the immediate post-war civil programme.

A treatment of the subject of high lift devices, as they still largely dreamed of them in 1949 in the form of multiple slotted flaps, would not be complete without pausing to pay a tribute to Dr. Hugo Junkers who proposed single and double slotted flaps no less than 28 years ago, in 1921. As a matter of interest Fig. J showed a typical example taken from his original Reichspatentampt No. 396621 (1921). From this it seemed only fair to observe that what Mr. Duddy referred to as the Fowler position was conceived at a much earlier date by Dr. Junkers, who placed his aerofoils in almost identical positions with those used today. Tests which he himself had made on the double slotted Junkers suggested that it was not greatly inferior to their present-day conception of this form of high lift device. What Mr. Fowler and others had done was to find means of retracting the flaps into the main aerofoil.

MR. DUDDY'S REPLY

Mr. Perring: If designers wanted a lift coefficient greater than 3 they would almost certainly have to go to a full-span leading edge slat and that put up the stalling incidence. If their aspect ratio was low—round about 6—the sort of incidence needed for landing would be of the order of 18 to 20 degrees and almost certainly a variable incidence arrangement would be required. But if they were considering a leading edge slat for civil aircraft with an aspect ratio of 10 or 12 then he thought there was a good chance of getting the required incidence, somewhere of the order of 14 or 16 degrees, by suitably shaping the fuselage and possibly by using rather longer undercarriages.

He entirely agreed on the necessity with future high speed aircraft of obtaining braking throughout the whole run. It was extremely important and he thought that some sort of mechanical device was wanted which would prevent the wheels from skidding. The pilot sitting up in front had little idea when his wheels started skidding and if they did skid at those high speeds they would wear out very quickly. He thought a device that would provide the actual braking pressure automatically was to be preferred to the present method, so that the pilot just pressed a button and the brakes came on

automatically just the right amount so that they did not cause the wheels to skid.

He thought if they tried to use boundary layer control on a flap where they were dealing with a turbulent boundary layer, then the quantities of air that they would have to carry away would be so large that it would be extremely difficult to conduct that air through the wing. If suction were used to control the laminar flow at the leading edge, that he thought would be practicable. The stalling incidence would be increased in much the same way as with a leading edge slat. He was not at all sure that the gain with suction would be more than the gain with a leading edge slat.

Mr. Foss: Unfortunately the position was that with large flaps they got quite large changes in trim due to slipstream, but they were not able to predict just what those trim changes would be. He therefore suggested that an adjustable tailplane was well worth while, certainly for prototype aircraft, until the precise changes due to slipstream could be measured. On very large flaps the trim changes could be very large and they could run out of elevator control unless it was augmented by an adjustable tailplane.

The airworthiness requirement that stated the flap should not be moved until speed had been reduced by something like 40 per cent. of landing speed, seemed rather severe he agreed. He would be in favour of some relaxation.

He had rather gathered at one stage that Mr. Foss was saying that because tail volumes had never been adopted they must be a bad thing. He did not think that was true at all; they certainly could have been adopted. The reason for using a large tail volume hinged primarily on the problem of maintaining longitudinal stability. The secondary effects mentioned during the lecture showed there were special reasons for using large tail volumes with large flaps. He was not trying to suggest that large tail volumes should be used simply because of those secondary effects.

He agreed that the trim change noticed by the pilot depended more on stick force than on stick position. This stick force trim change could certainly be controlled to some extent by a suitable choice of the elevator b_1. Unfortunately this quantity was normally determined by other considerations such as stick free stability. The use of positive b_1 to reduce effective trim change would only work if a very low tail volume were employed so that the flaps gave a nose-down pitching moment. He did not think there were many aircraft flying now which had a nose-down change of trim after putting the flaps down.

Altering the hinge line of the flap on a swept-back wing had been suggested for improving the lift increment. He had not seen the results of any tunnel tests on that idea, but presumably reduction of the sweep of the flap hinge line could only be obtained at the expense of either flap area or flap extension.

The difficulty of obtaining lateral control with full span flaps had not been mentioned in the lecture but was dealt with briefly in the paper. He thought that adequate lateral control was possible with a flap of at least 70 per cent. span and probably 75 per cent. If it were desired to go further and use a full span flap then he thought the best arrangement was to inset the aileron in the flap, as was done on the amphibian mentioned by Mr. Clifton. The only slight disadvantage was that it limited the deflection of the flap over the outboard part of the span—the part which included the aileron. If the greatest possible lift coefficient were required, then he thought some form of spoiler control would be necessary. This type of control had never been entirely satisfactory in the past due to the fact that the designer had to meet three difficult requirements. The controls had to have adequate power; it had to have adequate response; and it had to have a reasonable feel. Meeting those three requirements at once had been extremely difficult. With the possibility of using power operation the third requirement was automatically solved and the designer had only to satisfy two instead of three requirements, which was much easier. He thought there was a fair chance of success in that direction.

Mr. Foss suggested that aircraft using high lift flaps required a greater distance to "flatten out" before touch-down than aircraft with normal flaps. This effect would be expected when making engine-off glide approaches since the high lift flaps would probably reduce the L/D ratio and thus produce a steeper glide. The normal landing, however, was made at a fixed shallow gliding angle obtained by using a powered approach and was independent of the type of flaps used. In this case the distance to flatten out depended primarily on the approach speed and not on the type of flaps.

Mr. Clifton: He thought Mr. Clifton was rather modest in saying that his first aircraft with full span leading edge slots only had a maximum lift coefficient of 2.6. That was a very good effort because the size of the flaps on that aircraft were not particularly large. They were only half span and the chord was quite moderate, 20 or possibly 25 per cent., not more.

He thought the evidence so far suggested that the best type of flap was one which extended the chord of the aerofoil. This could be done with the ordinary split flap by moving the hinge point back towards the trailing edge as the flap deflected or, by using a slotted flap of the Fowler type. Very encouraging results had been obtained with those two types of flap on wings with sweepback up to 40 or 45 degrees. If the wings were swept back at angles more than 45° then trailing edge flaps gave little or no increase in maximum lift. Leading edge slats gave worthwhile increases in maximum lift even if only part span and they continued to be beneficial at more than 45° of sweepback.

Mr. Clifton was, he thought, the first to mention the matter of the weight penalty due to high lift devices. He supported the view that this aspect of high lift devices was extremely important and regretted it was outside the scope of the present paper.

Mr. Wood: The measured results of the York where the cut-out at the fuselage resulted in very little loss of lift coefficient compared with the estimated value, given by Mr. Wood was a fairly normal result. With a high, or a mid-wing position and with underslung nacelles the loss of lift increment due to the cut-out was usually quite small. On the average the loss was something like a half that calculated on the basis of loss in flap area.

The questions on trim changes due to power and optimum tail volumes had already been answered in reply to Mr. Foss. In reply to the repeated suggestion that large tail volumes were undesirable he pointed out that the Constellation, which was generally accepted as a very successful aeroplane, had a tail volume of 1.1.

Mr. Rowe: He agreed that in order to make use of the high lift devices they had to be pretty certain that the slow speed stability and control would be adequate. With regard to stability the evidence seemed to be that flaps did not have a seriously adverse effect on longitudinal stability but leading edge slats could certainly have disastrous effects on occasion. Mr. Rowe seemed rather doubtful about the suggestion that to obtain satisfactory lateral control with a 75 per cent. span flap all they had to do was to squash up the aileron. Tests had been made at the R.A.E. with an aileron which was almost square in plan; was 40 per cent. chord; had no forward balance at all but had a spring tab with a weak spring. In this arrangement the spring tab was in effect almost a servo tab and the results obtained were very promising. He had already mentioned in reply to Mr. Foss that the inset aileron provided a satisfactory solution to the lateral control problem with full span flaps.

He agreed that if the pilot were to make full use of high lift devices the designer had to ensure that the high lift device did not entail any marked reduction in either stability or control. In general this requirement was only likely to be troublesome when full span flaps were used. There was some evidence that full span flaps on wings with high taper ratios would cause unsatisfactory stalling characteristics. To cure this trouble the flap deflection over the outboard portion of the wing would have to be limited.

Tests had been made at the R.A.E. on two experimental high lift aircraft each of which had full span flaps and inset ailerons. Both those aircraft had adequate stability and reasonable stalling characteristics besides proving that an inset aileron could provide satisfactory lateral control.

The importance of flap drag during take-off had been mentioned in the lecture. The increase in flap drag due to slipstream was usually expressed as a reduction in the propulsive thrust of the airscrew. The estimates of take-off distances which had been made took full account of this effect which, in extreme cases, amounted to a reduction in propulsive thrust of almost 20 per cent.

Mr. Shove: He regretted that he was not qualified to prepare the paper on the weight and mechanical aspects of high lift devices suggested by Mr. Shove and Mr. Rowe. He agreed that such a paper would be most valuable in helping to determine the best type of flap for a particular aircraft.

The job would not be easy and he thought Mr. Shove was perhaps over-optimistic in looking for a simple relationship between flap weight per sq. ft. of flap area and ΔC_L. He thought that flap arrangements would have to be split into two groups; part span

and full span. For the various types of flap in each group it might be possible to determine an "efficiency" defined by a ratio such as ΔC_L times wing area over flap weight. There was a real danger that the final result might give a measure of the designer's ingenuity instead of a measure of a particular flap's structural advantage due to lack of sufficient data.

Mr. Salisbury: He was grateful to Mr. Salisbury for drawing attention to the error which occurred in the advance proof and apologised for not making the correction at the time of the lecture. He disagreed that his definition $\Delta C_{L\ trim}$ was misleading. Throughout the lecture $\Delta C_{L\ trim}$ referred to the change in maximum lift coefficient due to trimming out the pitching moment on the mainplane due to the flaps. This $\Delta C_{L\ trim}$, which was unaffected by the downwash over the tailplane, had an important bearing on the principal function of flaps, namely the change in maximum lift coefficient.

Mr. Lambert: He was sorry that Mr. Lambert had apparently been misled by the error in the advance proof referred to in the reply to Mr. Salisbury. He could not agree that a net gain in maximum lift due to trimming out the pitching moment of the flaps could only be obtained with a tail-first layout. With a conventional layout a gain in lift would usually be obtained if the centre of gravity was about 30 per cent. of the chord behind the aerodynamic centre; for adequate stability this would necessitate a tail volume coefficient of about 1.0.

Mr. Youngman: No attempt was made in the paper to describe all types of high lift flaps. The particular double slotted flap which had been mentioned was chosen because it was rapidly gaining favour among designers due presumably to certain structural advantages. This type of double-slotted flap—which might be described as slatted slotted—did not necessarily give the greatest lift increments or the least drag increments. He agreed that superior aerodynamic results were possible with the type of double slotted flap shown in Mr. Youngman's Fig. A. The disadvantage of this arrangement was that it was rather complicated and involved two separately moving flaps. The double slotted flap described in the paper could be made to move as one fixed unit. The type of double slotted Fowler he had recommended for future development would have a slat at its leading edge and since it would be moved as a single unit the structural and mechanical problems would be no worse than with a normal Fowler flap.

He was particularly interested in the results given by Mr. Youngman on small split flaps fitted to the trailing edge of much larger flaps. Similar results had been obtained in other tunnel tests but the idea had not as yet been tested in flight.

He agreed with Mr. Youngman that large wing root fillets might seriously reduce the effective span of high lift flaps. The possibility of doing away with such fillets or at least reducing the loss in lift due to root stalling by a small span leading edge slat was interesting and worthy of further development. It would probably be important to obtain a clean junction, without gaps, between the fuselage and the slat and this might be difficult in certain cases. He had sometimes wondered if a similar result might be obtained by fitting an extension to the wing leading edge at the root section; analogous to the dorsal fin for preventing fin stalling.

During a normal aerodrome take-off the increase in maximum lift coefficient due to slipstream was not used to any great extent but the drag in the slipstream did cause a considerable reduction in the propulsive thrust, as mentioned in reply to Mr. Rowe. The figures given in the table in the appendix did not include the slipstream effects. The reduction in propulsive thrust could be very great and he agreed it was an added reason for using the greatest possible flap span.

The simple full span flap achieved by fitting a split flap in front of a conventional aileron would probably reduce the aileron power by 10 or 20 per cent. and would necessitate rather large differential aileron movement. The arrangement was not really suitable for a twin-engined civil aircraft because the relatively high drag of the scheme would make it difficult to meet the stringent climb requirements. The scheme offered certain attractions for military aircraft with low power loadings, particularly those required to operate from aircraft carriers.

The point about the importance of the stick force trim change had been discussed in reply to Mr. Foss, but he wished to add that the trim change defined in the paper was

important for comparing different types of flap. The stick force trim change was unsatisfactory for this purpose since it depended largely on the detailed design of the elevator.

He agreed with Mr. Youngman that flaps had been used to increase the manœuvrability of aircraft, but he thought this was of secondary importance since practically any type of flap was suitable for this purpose.

The double slotted flap scheme patented by Dr. Junkers as long ago as 1921 was surprisingly similar to present-day designs. This lent support to the argument that such high lift devices had not been used by designers because they were afraid of the problems of stability and control in addition to the structural difficulties. The work done by the R.A.E. in recent years with two experimental high lift aircraft had shown that the stability and control problems could be solved and it was now up to the designers to devise means for overcoming the structural and mechanical difficulties. Mr. Youngman had achieved considerable advances in this direction by showing that complicated flap schemes could be operated by relatively simple link mechanisms.

THE AERODROME PROBLEM RELATED TO AIRCRAFT DESIGN AND OPERATION

by

R. H. AYERS, B.Sc., A.R.Ae.S.

THE AERODROME, as the point of contact between the aircraft and the world of reality, has to a large extent been taken for granted. The designer regards it as the base for prototype tests and the airline operator as his aerial railway station. It is my intention to show that aerodrome development is at a critical stage of evolution on this side of the Atlantic, that many of the related problems do concern the aircraft designer and operator, and that if these problems are not given consideration, difficulties will be encountered in civil operations.

To quote an example; the optimum aircraft type to serve a system of air routes can be worked out taking into consideration the range required, payload and speed, but if the aircraft ultimately ordered and produced cannot safely operate from the aerodromes to be served because of the runway length and approaches, then the operations will either have to be reorganised or continued without due regard for safety.

The natural reaction of the operator is that the aerodrome will be expanded to suit his operational requirements, but in the present economic circumstances this seldom happens. The average citizen in Europe today will not agree to the loss of arable land or demolition of farm buildings, or factories, so that runways can be extended to enable wealthier citizens to cruise through the sky in aircraft 100 m.p.h. faster than their pre-war counterpart.

The present situation can best be understood by a brief review of the history of the civil aerodromes now in use. Those with any claim to having been selected to serve a particular centre of population for civil use were small grass fields in pre-war days, usually sponsored by the municipal authorities. A take-off run of 4,000 ft. was adequate and often the town development spread to the airfield boundaries. Radio approach aids and control services were almost non-existent. The terminal buildings were situated on the perimeter of the field.

When war came the country was covered with some hundreds of runwayed aerodromes sited for military purposes well away from towns. Scarcely a single new first-class aerodrome was built within 15 miles of a town which could justify its own aerodrome. At a distance of 15 miles or more an aerodrome can hardly be considered to serve a town with reasonable hope of success for internal services because of the time lost in travel from the town, and the economic drag which the surface transport operation throws on to the airline operator.

Some of the pre-war municipal grass aerodromes were enlarged and equipped with runways and the typical perimeter track which characterises all military airfields for dispersal purposes, was laid down. Buildings and hangars were installed with the main accent on de-centralisation. Thus, at the end of the war, this country and many others in Europe were provided with a large number of aerodromes suitable for post-war aircraft types, but ill suited for civil operations. Those aerodromes nearest the towns are the smallest because of their pre-war beginnings and limitations imposed by the town buildings.

Following such a vast expenditure of capital on aerodrome development during the war, it is easy to appreciate the lack of public understanding of the present shortage of adequate civil aerodromes, and the natural reluctance, or economic incapacity, of European countries to build a system of civil aerodromes sited and suited for civil requirements. That is the first and most

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Mr. Ayers is Head of an Air Safety Section, Ministry of Civil Aviation. The views expressed in this paper are not necessarily official views.

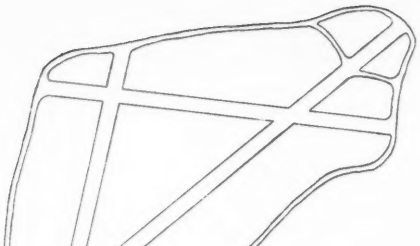

Fig. 1.
Typical military layout.

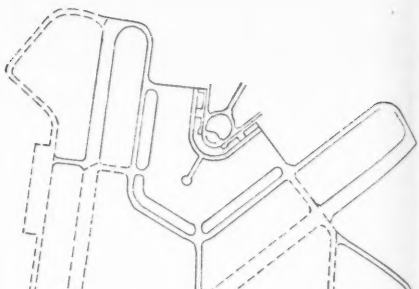

Fig. 2.
Typical civil airport conversion.

important consideration which must be realised, and while it is illogical that civil aircraft design should be stifled by aerodrome limitations, yet it is none the less an undeniable fact that unless aircraft can fit into the small civil fields near the towns it is unlikely that they will be brought into operational use. As an example, the *average* main runway length of the aerodromes serving the 12 major towns in the United Kingdom, excluding London, is 1,400 yds. and aircraft requiring a main runway of more than 1,200 yds. are unlikely to prove useful for internal services in the United Kingdom.

Runway lengths must obviously be related to aircraft take-off and landing performance before the designer can determine the precise extent of the aerodrome limitation on his design characteristics. The ideal relationship between runway length and performance is that the runway should be long enough to permit re-landing the aircraft in the event of power failure occurring after take-off at any speed below safety speed. Adequate time lag must also be permitted for the pilot to predetermine his course of action and carry out his feathering procedure.

The desirable state of providing 100 per cent. for emergencies cannot be met by available runway lengths and the main runway length may have to be accepted as the take-off distance to clear a 50 ft. screen at minimum safety speed, or landing to rest from 50 ft. screen under nil wind conditions.*

Effort to establish a more detailed formula relating runway length to performance will probably result in failure, because of the wide range of performance figures recorded for the best and worst aircraft of a type and the variety in handling technique. The runway length required should be determined for the type at its official acceptance tests and quoted on the Certificate of Airworthiness for standard temperature, pressure, runway and loading conditions. This is already being done in the United States.

If the performance criterion is accepted, it must be borne in mind that this gives the main runway length and allows for instrument approaches and the necessary margin due to a less precise landing and an instrument landing system leading to a touch-down some distance from the beginning of the runway. Subsidiary non-instrument runways are usually 84 per cent. of the main runway length under International Civil Aviation Organisation standards, and are often as low as 60 per cent. because of site limitations.

* This standard is now incorporated in legislation, but the 50 ft. screen landing distance has to be 70 per cent. of the available runway in I.F.R. conditions and 80 per cent. in V.F.R. conditions.

The military and civil requirements for runways, their attendant instrument aids and radio airfield control facilities, are similar, although the civil safety requirements dictate considerably longer runways for equivalent types. Civil requirements demand a central terminal building, apron and radial taxiway layout as distinct from the military perimeter track layout with dispersed buildings. Figs. 1 and 2 show a typical military layout and a typical civil plan. Large grass areas on runwayed aerodromes are a liability in upkeep, except insofar as grass drying is a revenue-earning aspect.

The ideal situation for a terminal apron is as near the centre of the field as can be arranged, in order to reduce taxi-ing with its waste of fuel and time. Thus an obvious move when converting some military aerodromes for civil use is to site the apron and terminal buildings within the existing perimeter track, thus using up an otherwise wasted grass area and bringing it towards the focus of the runway system.

Communication facilities by rail and road from the town served must be all-important in determining terminal area siting, and future road planning may enter the picture.

The runway layout is determined by consideration of the usability factor to be achieved, having regard to a certain maximum cross-wind component which can be accepted during landing. The meteorological data for the site indicates whether three runways are necessary. In monsoon areas where the seasonal winds are S.W. and N.E. a single runway gives excellent coverage for all seasons and is an ideally simple layout. In this country we accept at present a three-runway pattern.

The accepted maximum cross-wind component is 15 m.p.h. and a usability of approximately 97 per cent. is the aim. A steady 15 m.p.h. ground wind is found to give gusts up to twice that amount and this ratio of gusts to steady wind is normally applicable throughout the scale. If the acceptable cross winds can be raised from 15 m.p.h. to 20 m.p.h. the saving in runway costs in the United Kingdom alone will run into millions of pounds. A runway for a modern "giant" aircraft may cost £3 per square yard which gives almost £1 million as the cost of a 10,000 ft. runway 300 ft. wide.

To accept 20 m.p.h. cross winds the design demand is inherent directional stability on the ground, given only by a tricycle undercarriage, and the strength to accept with a safety margin the side thrust imposed by a possible 40 m.p.h. gust. The pilot ability to cope with these conditions demands a high standard of skill and concentration, even though a castoring undercarriage eases the design problem, but I feel sure this skill can be relied upon and I think we shall accept this standard in the near future.

The average two-runway layout usability in this country is usually below 90 per cent. with a 15 m.p.h. cross-wind component, but increases to approximately 97 per cent. if the cross wind acceptable is raised to 20 m.p.h. It is obvious that apart from cost, the two-runway layout is the designer's dream, giving ideal terminal location at the heart of the runway system with perfect accessibility and room for expansion (see Fig. 3).

The desirability of spreading the weight by multiple wheel installation and low tyre pressure cannot be too strongly emphasised again because of the economic difficulties of strengthening war-time runways to cope permanently with regular services of heavy machines.

The next problem associated with civil airfields concerns the surrounding buildings and the approaches to the runways. By virtue of the necessity of being close to a centre of population, it is usual to find buildings near the aerodrome and while in this country the Town Planning Act allows

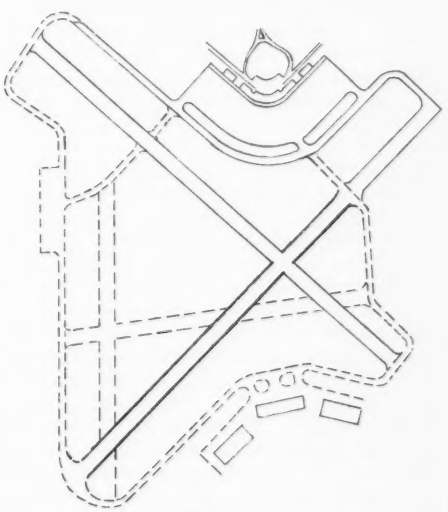

Fig. 3.
Ideal two runway conversion for civil use.

a measure of control over new buildings, the problem of the demolition of existing structures which form obstructions is no easy one. Such obstructions may be factory chimneys, power stations, shipyard cranes, and so on, and a moment's consideration of the present economic circumstances indicates the difficulties involved.

The solution lies, to a large extent, in the hands of the operator. There is a widespread idea that modern aircraft must approach at an incredibly flat angle. The I.C.A.O. standard instrument runway design approach gradient is 1:50, or a little over 1° above the horizontal. This represents a rate of descent of 175 ft./min. at 100 m.p.h. approach speed. Against this, both a Skymaster and a Constellation have been brought in and landed successfully in a throttle-closed approach at an angle of 1:7 or 8°, the rate of descent being 1,700 ft./min. This is an extreme, but I suggest that a final approach, at a rate of descent of 800 ft./min., could be made standard without detriment to passengers' comfort.

With a final turn in at 800 ft. this rate of descent would only last one minute and the approach would be only two miles long, instead of the modern dragged approach lasting some six miles. Operators could achieve this tidy circuit pattern by specifying a standard average approach power setting which would achieve this rate of descent. This would give an operational approach angle which could be adopted for instrument approach aids of 4° or 1:15. An overall aerodrome design standard of 1:30 would give an adequate safety margin and be considerably more realistic and easier to administer than 1:50.

Apart from the need to avoid the obstructions which do exist, in spite of I.C.A.O., an almost equally important result to be achieved is a reduction in noise level to the surrounding inhabitants. With the noise level varying inversely as the square of the height, an approach at a rate of descent of 800 ft./min. gives only 25 per cent. of the noise caused by a 400 ft./min. descent, ignoring the additional gain caused by lower power setting. The smaller circuit also results in noise disturbance over a smaller area. Pressurisation of cabins removes the last excuse for low flying during approach or after take-off on the excuse of studying passengers' comfort, as the change of cabin pressure can be controlled independently of external pressure change.

The ultimate efficiency of an aerodrome must be measured in terms of the movement rate achieved. A high movement rate depends on the team work between control and the operator, but more especially on quick runway clearances during take-off and landing and correct circuit spacing of aircraft prior to landing. While this spacing is the pilot's responsibility, he can make or mar the results. As an example, if a movement rate of 30 aircraft per hour total in and out is the aim, then the average spacing is two minutes between movements, or a circuit distance of four miles between consecutive landing aircraft, assuming circuit speeds of the order of 120 m.p.h.

In view of the somewhat depressing aerodrome situation and the unfortunate necessity for conversion from military to civil requirements, a master plan of development for each chosen airfield must be determined at an early stage. Building conversions, new structures and demolitions are involved in the conversion, however slow the progress towards the ultimate goal and if these are done piecemeal, the result will be chaos with much waste of capital.

A civil airport must be constructed with an eye to its future, lasting between 20 and 50 years, and for this reason the all-important factors in considering aerodrome siting and development are those with most permanence.

In order of importance it is suggested that these factors are:—

(1) Travel time from the town to be served.
(2) Size of the centre of population to be served.
(3) Geographical location of the town served, *e.g.* on an island.
(4) Possibilities of site.
(5) Meteorology of site.
(6) Routes to be served.
(7) Aircraft types to be operated.

The master plan must take account of the existing, and possible ultimate, runway system, terminal area location, having regard to road and rail access from the town, aircraft maintenance area, aircraft parking area with servicing hangar for use by aircraft stopping over for periods greater than one hour. A freight handling hangar and apron should be included in the plan.

The design data which seems reasonable by present standards is an aircraft movement rate of 30 per hour total in and out

for a single runway system, with passenger handling space for a peak of 1,000 passengers per hour. Terminal apron should provide approximately 12 loading bays with complete accessibility. This requires a possible apron length (and building frontage) of 1,500 ft. and apron width of 400 ft.

An average turn-round time of approximately 50 mins. is used in determining the number of loading bays, *i.e.* 30 movements per hour gives an average of 15 inward movements per hour, and assuming each stops 50 mins., 12 bays are required. This can only be achieved by good aircraft design which has taken into consideration speed of refuelling, accessibility of loading hatches and minor servicing points.

The parking area for aircraft being serviced during a longer stop-over should be adjacent to the apron and provide for some eight additional aircraft. The maintenance area site may be determined by existing military hangars. A freight area with freight storage hangar should be planned near the apron, with independent road access. As the Customs Officials will be concerned with freight clearance, the location of the main Customs Office should be borne in mind when locating this area.

The possibility of adding amenities such as a swimming pool and tennis courts, rendering the airport both attractive and lucrative, must not be forgotten in the overall plan. The conclusion reached is that the aerodrome problem must, to a large extent, dictate the future and it is thought that jet aircraft development will be considerably delayed by such problems as runway length, effect of hot blasts on runway surfaces and passengers, and the traffic control scheme to be applied to fast aircraft with high fuel consumption at low altitude.

To summarise, the aircraft design and operational features which are so important in assisting to solve the aerodrome problem are:—

(1) Short runway requirement.

(2) Directional stability on the ground with undercarriage strength to accept high cross winds.

(3) Climb and let down rates in proportion to the horizontal speed, giving reasonable approach and take-off angles.

(4) Multiple wheel undercarriages to spread aircraft load and keep runway strength requirement down.

(5) Passenger, fuel and cargo loading arrangements for quick turn-round times.

(6) Reduction in aircraft noise during take-off and landing, having regard to populated areas near airports and the continuous nature of the operations.

(7) High traffic movement rates by rapid clearance of runways and team work during landing and take-off operations.

(*Correspondence on this subject will be welcomed.*—EDITOR.)

THE WEIGHT OF SEAPLANE FLOATS

by

L. W. ROSENTHAL, A.F.R.Ae.S., M.I.Ae.S.

INTRODUCTION

Although floatplanes were not popular during the war years, new types have made their appearance since, and presumably, for certain classes of work, more will be seen in the future. With this in mind, this paper is presented in the hope that it may help in assessing the float weights on any new designs that are contemplated. Some suggestions are included concerning geometry and design which, if adopted, may help to show a higher weight efficiency than existing practice.

The paper is based upon an analysis of the weight and geometrical data relating to a large number of floats, although since the number built during recent years is small, a certain amount of data, which might possibly be considered old by some standards, has been incorporated. As will be seen by the curves, recent practice shows no radical departure from earlier years and the inclusion of the early data to establish design trends would appear to be warranted.

The weights of recent floats, too, show no improvement on the older types, although should a new series of floats be built incorporating new ideas and modern high strength alloys, some modification of the weight curve may eventually be necessary.

DIMENSIONS

Following an approach used in finding the effect of gross weight upon hull and fuselage dimensions[1], the length, depth, and beam have been plotted against the cube root of the buoyancy in Fig. 1. Although the plots cover floats for aircraft ranging from 2,000 lb., to 20,000 lb. all-up weight, designed over a long period of time, the deviation from these curves is remarkably small, particularly in the cases of length and depth. The consistency of the relationship between size and buoyancy is clearly illustrated, and when laying out new floats of orthodox shape, these curves can be used to establish the preliminary major dimensions.

SURFACE AREA

Following along the approach used for the dimensions, the surface area has been plotted against the two-thirds root of the buoyancy in Fig. 2, where again the deviation from the curve is remarkably small. In the early design stage this curve will be found satisfactory for assessing float surface area for drag purposes, besides providing a good background for the estimation of plating weight.

Surface area is to some extent controllable and may be reduced by going towards shorter, fatter floats, and since the weight must be affected by area, this should lead to lighter floats. Fig. 3 gives a plot of buoyancy divided by area and, in new designs, the aim should be to fall above the curve indicated.

WEIGHTS

Although weight must be affected by surface area, all attempts to establish any relationship had to be abandoned because of the wide scatter of the plots.

When weight is plotted against buoyancy, however, quite reasonable results are obtained, and the curve is given in Fig. 4. When assessing the accuracy of the expression developed from this curve, it was found that the estimated weights of 51 per cent. of the floats considered were within ± 5 per cent., 70 per cent. within $\pm 7\frac{1}{2}$ per cent. and 83 per cent. within 10 per cent. of their actual weighed weights. This means that it should now be possible to estimate the weight of a pair of normal seaplane floats to an accuracy of approximately one per cent. of the aircraft gross weight.

Paper received April 1949.

Mr. Rosenthal is Chief Weight Engineer, Saunders-Roe Ltd.

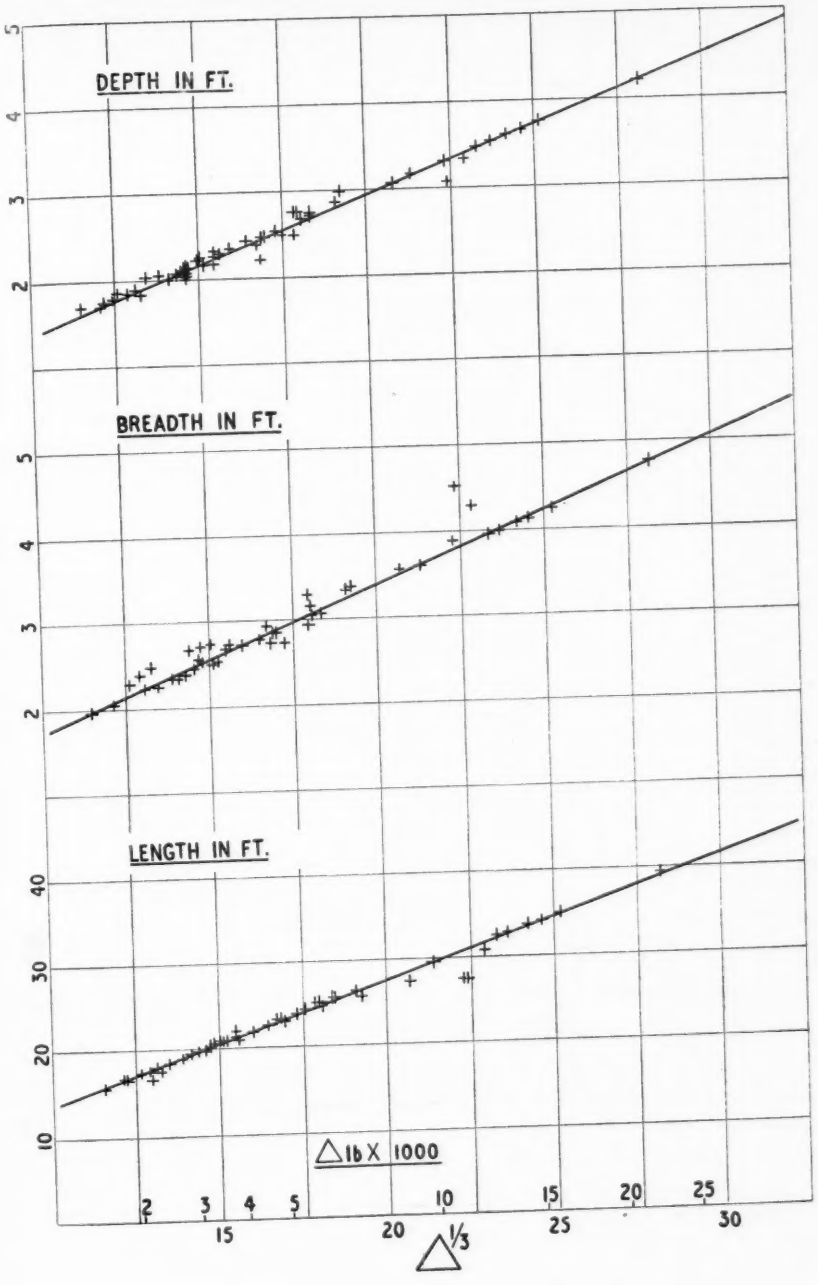

Fig. 1.
Float dimensions.

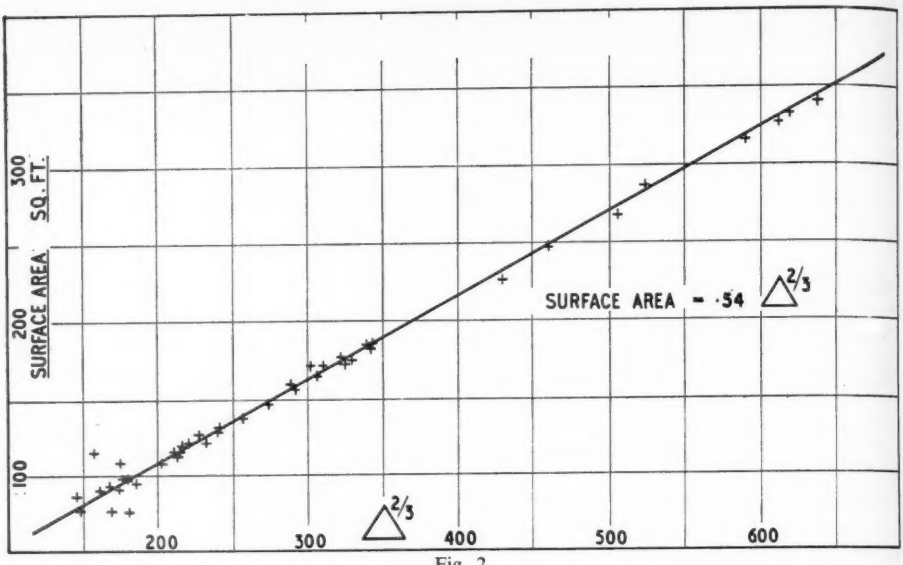

Fig. 2.
Surface area.

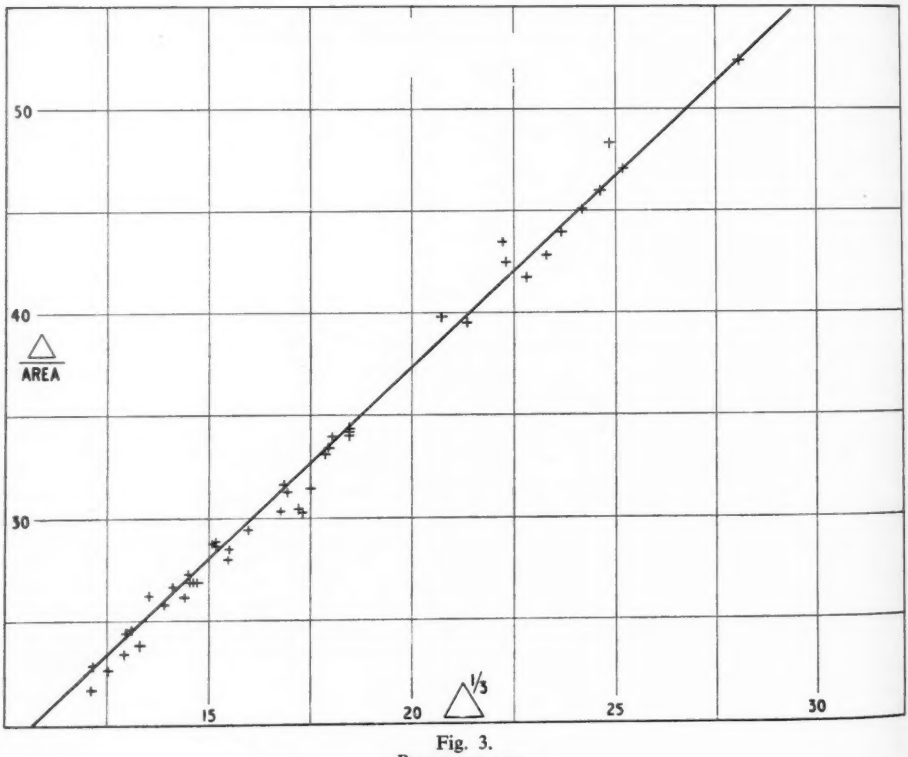

Fig. 3.
Buoyancy area.

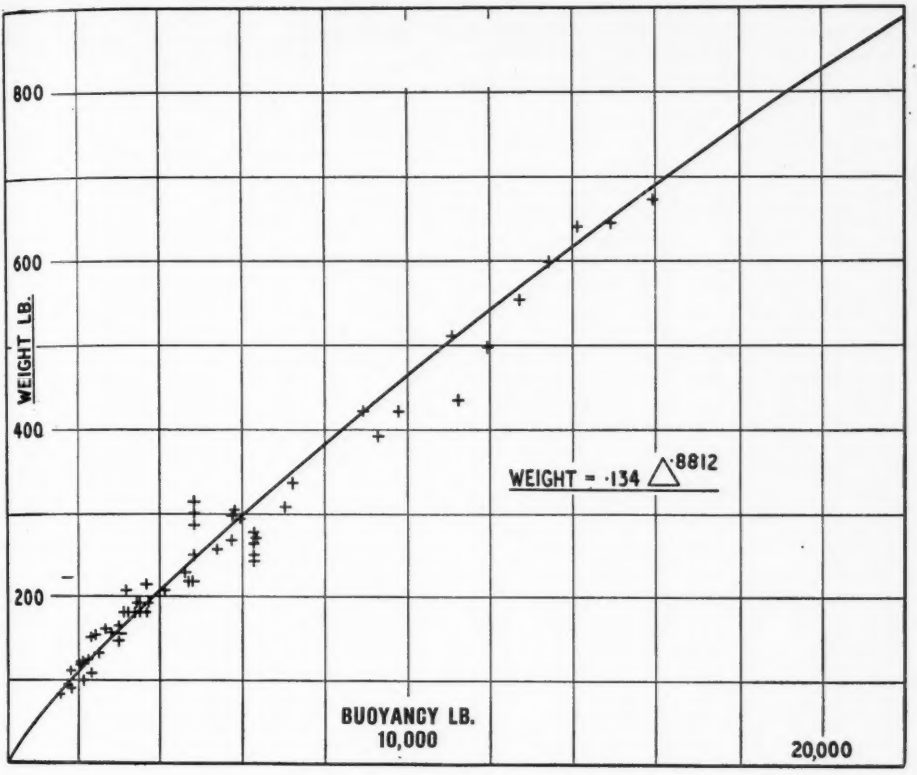

Fig. 4.
Float weight.

The shape of the float, while being of considerable importance from hydrodynamic aspect, can have a serious influence upon the weight. The average length to depth ratio is approximately 9, and any proposal to increase this figure for hydrodynamic reasons should be resisted until the full merits of the case have been examined. The existing design cases for floats[2], *i.e.* bow and two wave landing cases penalise long shallow floats, consequently to produce a float of light weight, the length to depth ratio should be as small as possible.

The use of alloys of higher strength than those used in the past, unfortunately, is not likely to show much improvement on the weight. The major item of weight is generally the plating and, on small floats at least, the gauge of much of this appears to be determined by practical rather than strength, considerations.

Because the plating weight is generally the heaviest component of the float, every effort should be concentrated on cutting down the gauges, and one effective method of weight saving on the plating is by using "odd," as well as "even" gauges. Strangely enough this method of weight saving does not appear to have been much exploited on floats, or for that matter on any aircraft component.

The selection of the optimum frame spacing is another point which must be watched if plating weight is to be kept to a minimum.

On small floats it will be found that a fairly close frame spacing will probably give the lightest results, whereas on larger

floats where the frame weight is a bigger proportion of the total, the answer will not be easily arrived at, and individual investigation is probably the only way of determining the optimum layout.

The design of the secondary and non-structural parts of the float are of considerable importance, since these are responsible for up to 25 per cent. of the float weight. To justify the effort normally put into the problem of keeping the structure weight to a minimum, similar attention must be given to the non-structural items, particularly where they are likely to be used or copied on succeeding designs.

In this connection, the location and method of attaching the chassis struts needs careful consideration. Cutting the top deck to facilitate fairing in the strut attachments should be avoided if at all possible, since this causes discontinuities in the main bending structure, resulting in weight increases and difficult structural problems.

CONCLUSION

Although there appears to have been little progress so far in the design of floats, when considered from a weight aspect, in common with other airframe components some improvement can be expected in the future.

It is hoped that the ideas put forward in this paper will assist in this trend, and for convenience they are summarised as:—

1. Selection of the optimum geometry
2. The use of "odd," as well as "even" gauges of plate
3. Selection of optimum frame spacing
4. Careful design of secondary and non-structural items.

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REVIEWS

REISSNER ANNIVERSARY VOLUME; CONTRIBUTIONS TO APPLIED MECHANICS. Polytechnic Institute of Brooklyn. J. W. Edwards. Ann Arbour, Michigan. 1949. 493 pp. $6.50.

The custom of addressing to notabilities elaborate compliments died in Europe with the First Gentleman and le Roi Soleil; the practice of dedication to them of works of literature fell even earlier into disuse. It is remarkable that in the New World both practices are now being revived in favour of the new aristocracy of Science.

The younger contemporaries of a doyen of the profession combine to mark the occasion of one of the later anniversaries of his birthday by the publication of a dedicatory volume epitomising his achievement and underlining it by contributions of their own. Stephen Timoshenko, Theodore von Kármán, and now Hans J. Reissner have been thus honoured by their associates, and the task of the reviewer grows Herculean. Just as "the unusual breadth of Dr. Reissner's scientific interest is manifested in the variety of subjects upon which he wrote," so is his tremendous influence on the development of science in the United States evidenced by the scope of the contributions inscribed to his honour. Even the omniscience of the reviewer is shamed by confrontation with a collection of papers on so many subjects over such eminent names. The only course possible in logic would be to enlist an even larger body of still younger workers to construct a thorough critical appreciation. Yet would it be seemly to peer too closely into works so hallowed by their occasion?

The present volume might be likened somewhat to "The Prince," by Machiavelli, in that it epitomises some of our present means to the Government of Nature. To a humanist it is disquieting to consider the nature of the achievement it illustrates and to reflect upon the implications of the aristocracy such works elevate. Our new aristocrats must have a pretty taste in mathematics as Cesare Borgia had in dress. Do we demand no other qualifications?—H.L.C.

ROCKET PROPULSION ELEMENTS—AN INTRODUCTION TO THE ENGINEERING OF ROCKETS. George P. Sutton, M.S. John Wiley, 1949. 294 pp., photographs, diagrams, bib. 27s. net.

During the last decade, it has become abundantly clear that the liquid propellant rocket is one of the vital new factors in aeronautics, or indeed in human affairs generally. It will play an increasing part in the fields of take-off assistance and the propulsion of very high-speed, high-altitude, aircraft, while as a pure missile it has obviously come to stay in the military scene. Neither must it be forgotten that all those branches of science—physics, meteorology, astronomy and radio—which are concerned with conditions in the upper atmosphere and beyond, must owe a mounting debt to the high altitude research rocket; efforts in this latter direction will lead gradually but inevitably towards the ultimate achievement of interplanetary flight, if those most closely concerned are to be believed.

In view of this state of affairs, it is surprising that until now no really comprehensive technical book on the subject has been published, written from the viewpoint of the design and development engineer. There were, it is true, the pre-war works of such Continental pioneers as Oberth and Sänger, but these must now be regarded as classics rather than modern texts. For the rest, there have been only a number of popular and semi-popular books (some excellent of their kind), dealing primarily

with the possibilities of space travel, and some highly mathematical volumes mainly concerned with the ballistics of rocket projectiles. On the most novel of all the many aspects of the subject, the liquid propellant rocket power plant itself, the earnest seeker after information could do no better than wade through the mass of periodical literature, which has been considerable, in spite of security considerations.

The situation has now been remedied by the excellent work under review. Its author is Supervisor of Propulsion Development with North American Aviation, Inc., and his book is founded on a series of lectures delivered before post graduate students of the University of California. A useful feature is the series of questions given at the end of each chapter, in the usual manner of a technical textbook; much information is clearly and concisely tabulated, and the symbols used in mathematical discussion are collected together and well defined.

There are a few aspects of rocket technology which are not covered, at least in broad outline, but the main emphasis throughout is on the engineering problems of the liquid rocket motor. After brief introductory chapters defining terms and outlining rocket history, the author deals at some length with supersonic flow through nozzles, dissociation phenomena (which are so important at the high combustion temperatures often involved), the general thermo-chemistry of different propellant combinations, and the extremely severe heat transfer problems which arise. He discusses the practical handling difficulties of rocket propellants and the mechanical design of suitable control valves, propellant injectors and other components.

There is a single chapter on solid rockets, which are shown to be heavier than the liquid type for long burning times. As the required duration increases, it is at first preferable to use compressed gas, to feed liquid propellants, then (for still longer periods) to employ a turbo-pump system like that of V.2. Other chapters briefly discuss rocket testing and the calculation of rocket projectile trajectories. In the latter, there is a section on space travel, of which Mr. Sutton states: "Although these and many other problems will require years of development and research, the basic physical question as to whether a vehicle can escape the earth has been theoretically solved."

In a single volume of this length, much must inevitably be left unsaid; recognising this, the author has submitted his work only as an introduction to the subject, referring his readers to detailed specialist sources through the excellent bibliographies provided at the conclusion of each chapter. He is to be congratulated on having succeeded extremely well in his object. He has produced a comprehensive study which can be thoroughly recommended to all those working on rockets, or desiring a better understanding of their immense possibilities (and their limitations) in connection with aircraft propulsion.—A.V.C.

SO YOU WANT TO ENTER CIVIL AVIATION. V. E. Mearles. *Daily Mail* Publications, New Carmelite House, London. 1949. 119 pp. 18 illustrations. 2s. 6d. net.

This is No. 12 of "Careers of Today Series."

The first eleven in this series offer you other careers before you decide whether No. 12 is worth while. If you happened to have spent your half-crown on No. 11, for example, you might become a Commercial Artist. Considering the way civil aviation is going places (and bringing you back, see advertisements) and considering also its ownership, it might be useful to buy No. 10, "So you want to enter Local Government." It would strain one's loyalties too much, however, to buy No. 4, "So you want to be an Accountant," and *then* suggest you buy No. 12.

This book will interest all those who believe they will, sooner or later, make a career in civil aviation. There are many opportunities for those who are prepared to begin slowly on the ground floor and work upwards to 40,000 feet at supersonic speeds where you cannot always hear yourself speak.

It is a book full of information of where to go and what you may get when you have got there, but whether books of this kind ever decide a career the reviewer is not prepared to say, although he has heard of young men who have decided they wish to design aeroplanes because they knew someone who had once built a model which was taken up by one of the leading aircraft firms in the country as the prototype of the largest passenger machine now in production.

If you are that kind of young man then your half-crown will be well spent, for you will enjoy knowing how to become anything from a pilot (one commends especially the first paragraph of Chapter 2) to a steward or a stewardess (including cooking, washing up, and "voyage procedure").

STREAMLINE FLOW. H. F. P. Purday. Constable and Co. Ltd., 1949. 185 pages. Bibliography. Index. 18s. net.

It is perhaps commonplace to note that there are groups of subjects of physics and engineering science that share basic principles and methods. Yet no student can fail to be stimulated when examples of such groups are presented to him, and in a text book on one subject some discussion of the analogous subjects can be of great value. In this respect Mr. Purday's little book is particularly commendable. Its main aim is to provide an introduction to the allied subjects of non-turbulent and, in particular, viscous flow, film lubrication, heat conduction and heat transfer in non-turbulent flow. Where possible, however, illustrations of basic principles are also drawn from the analogous topics of torsion of prisms, deflections of membranes, diffusion, vibration of strings and so on.

After an introductory chapter on viscosity, viscous flow in parallel pipes and channels is dealt with in some detail, and the basic equation is derived relating the pressure gradient in the direction of flow (constant across any section) and the velocity, namely $\frac{dp}{dx} = \lambda \nabla^2 u$. Simple but illuminating approximate solutions are then obtained for the flow in tubes of rectangular sections of various aspect ratios, including square section, as well as in tubes of circular and elliptic sections and in annular channels. Then follows a discussion of viscous flow between fixed parallel planes, and the existence of a potential function for the mean flow (as illustrated by the Hele-Shaw apparatus) is established. The solution for the flow under a rectanguar plate with uniform flow into one side is then derived in successive stages of approximation. This is followed by a discussion of the flow in a film of uniform thickness varying with time, for which the general equation can be readily related to the above equation for viscous flow in a parallel tube (Poisson's equation). Solutions for the latter problem can therefore be readily adapted to give solutions of the former problem.

The flow in a film of thickness varying in space is next considered and the general equation for sliding pads is derived. The problem of a sliding pad at a small angle of attack is dealt with in some detail, the discussion covering in an approximate but effective manner the cases of the rectangular pad of finite aspect ratio and the film of non-linear taper. Considerable space is devoted to the pad of parabolic section of infinite and finite aspect ratio, as this provides the basis for the discussion of journal bearings that follows.

In a chapter on the viscous resistance of bodies the formulæ for the viscous drags at very low Reynolds numbers are summarised for spheres, spheroids, ellipsoids, elliptical discs, circular and elliptical cylinders. These are followed by an elementary discussion of the skin friction in a laminar boundary layer on a flat plate in a uniform stream with a brief reference to the corresponding results when the boundary layer is partly or wholly turbulent. Here the author might usefully have referred to the more up-to-date information given in the Royal Aeronautical Society Aerodynamic Data Sheets.

The next three chapters present an elementary discussion of some problems in the flow of heat. A few simple but important examples of heat conduction in one dimension are given, followed by the derivation of Fourier's equations for heat conduction for two and three dimensions. Simplified versions of the theory of forced convection in a uniform tube and in a laminar boundary layer with uniform external flow are developed. The treatment of the latter is in effect based on the energy integral equation assuming a linear velocity profile and neglecting the heat due to viscous dissipation. The problem of forced convection in a channel is then considered in some detail without introducing the assumption of a thin boundary layer.

A brief but pertinent discussion of orthogonal functions is given in the next chapter, and the final chapter presents the Navier-Stokes equations (with constant viscosity) and a summary of the special forms that arise when compressibility, viscosity or inertia are neglected.

The book is in the main designed to meet the needs of the practical engineer wishing to become familiar with the theory of the subject, but there is much in the book that should be of value to the theoretical worker in a wide range of subjects. It is liberally supplied with examples and useful tables, and the occasional but relevant digressions into mathematical theory are a valuable feature. The style is clear and concise and the layout is attractive. There are very few misprints, and none are misleading; the reviewer noted the wrong numbering of the equations referred to on Fig. 29.2 (p. 45) and again the wrong equation is referred to for the constant C on p. 62. A minor criticism that might be made is that the examples would have been more effective had they been presented in the form of question and answer. There is an ample bibliography and index.—A.D.Y.

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THE ROYAL AERONAUTICAL SOCIETY

4 HAMILTON PLACE, PICCADILLY, LONDON, W.1. GROSVENOR 3515-9

NOTICES SEPTEMBER 1949

CONTENTS OF SEPTEMBER JOURNAL

Investigation of Aircraft Accidents in Relation to Aircraft Design, by Air Commodore Vernon Brown, C.B., O.B.E., M.A., F.R.Ae.S.
High Lift Devices and Their Use, by R. R. Duddy, A.F.R.Ae.S.
The Aerodrome Problem Related to Aircraft Design and Operation, by R. H. Ayers, B.Sc., A.R.Ae.S.
Weight of Seaplane Floats, by L. W. Rosenthal, A.F.R.Ae.S.
Reviews.

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the Journal and hope that members and non-members will contribute papers on their own special subjects.

THE AERONAUTICAL QUARTERLY

The second number of " The Aeronautical Quarterly " was published in August. Copies are obtainable from the offices of the Society, 4 Hamilton Place, W.1, at 7s. 9d. each to members of the Society, post paid, or 10s. 3d. each to non-members. The contents of the second number are:—

Displacements of a Linear Elastic System under a Given Transient Load	D. Williams
Skin Friction in the Laminar Boundary Layer in Compressible Flow	A. D. Young
The Measurement of Gas Turbine Combustion Efficiency by Gas Analysis	L. J. Richards and J. C. Street
A Simplified Theory of " Simple Waves "	A. Ghaffari

The first number, of which copies are still available, contains the following papers:—

Control Reversal Effects on Swept-back Wings	H. Templeton
Calculation of Downwash Behind a Supersonic Wing ..	G. N. Ward
Estimation of the Effects of a Parameter Change on the Roots of Stability Equations	K. Mitchell
Flutter of Systems with Many Freedoms	W. J. Duncan
Note on Propeller-Turbine Reduction Methods	E. C. Pike
Determination of the Drag of Jet-Propelled Aircraft in Flight	G. W. Trevelyan and D. R. Blundell
Notes on the Linear Theory of Incompressible Flow Round Symmetrical Swept-back Wings at Zero Lift	F. Ursell

The special attention of members is drawn to the fact that a strictly limited edition only of " The Aeronautical Quarterly " is printed and numbers cannot be reprinted in any circumstances.

CHARTER SCHOLARSHIP

The first award of the Royal Aeronautical Society Charter Scholarship has been made to JOHN ANTHONY DUNSBY, B.Sc. Mr. Dunsby, a Student of the Society, has been given a Scholarship of £300 for the year 1949-1950 and will take a Post-Graduate Course in Aeronautics at the Imperial College of Science and Technology.

THE SOCIETY'S LECTURES

The Council have decided to extend the Society's lecture programme to include subjects of specialised interest ranging over the many different branches of aeronautical science and engineering.

To interest the specialist and to assist the junior members of the Society a series of special lectures (called Section Lectures) are being arranged in the Society's library. Five of these additional lectures will be held in the Autumn Session and upon their success will depend the extension of the scheme. The Section Lectures will be of two main types:—

(*a*) An exposition on a subject by an expert on the lines of a University Lecture occupying 40 to 50 minutes, followed by a discussion in which the audience will ask questions rather than make additional contributions to the subject. No pre-prints will be available normally for this type of lecture.

All the Section Lectures arranged for the Autumn Session are of this type.

(*b*) A " Discussion Evening " which will be opened by a lecturer presenting the main points of his paper in not more than 10 minutes, followed by a general discussion.

If the success of the Section Lecture is established, a number of these will be read out of London.

Although all Main Society Lectures will continue to be published in the JOURNAL it is not proposed that the Section lectures or the Discussions should automatically be published.

LECTURE SESSION, AUTUMN 1949—MAIN LECTURES

(*To be held at* 6 *p.m. at the Institution of Civil Engineers, Gt. George Street, S.W.*1, *unless otherwise stated. Tea will be served at* 5.30 *p.m.*)

Thursday, 15th September 1949—Fifth British Commonwealth and Empire Lecture—Inter-City Transport Development on the Commonwealth Routes, E. H. Atkin, B.Sc., F.R.Ae.S.

Thursday, 6th October 1949—Aircraft Design Analysis Methods as Employed by the Research Division of the Bureau of Aeronautics, U.S. Navy Department, I. Driggs, F.R.Ae.S.

Thursday, 24th November 1949—AT BRISTOL—A Review of Aerodynamic Cleanness, E. J. Richards, M.A., A.F.R.Ae.S.

(*At* 7.15 *p.m. at the Royal Fort Physics Laboratory, Bristol*)

Thursday, 1st December 1949—The Weight Aspect in Aircraft Design, L. W. Rosenthal, A.F.R.Ae.S.

Thursday, 15th December 1949—JOINT LECTURE WITH THE INSTITUTE OF NAVIGATION—Navigational Systems and Instrument Aids, Dr. D. E. Adams, B.Sc., A.Inst.P., and Dr. A. N. Uttley, B.Sc., Ph.D.

LECTURE SESSION, AUTUMN 1949—SECTION LECTURES

(*To be held at* 7 *p.m. in the Library of the Society, at* 4 *Hamilton Place, W.*1)

Tuesday, 18th October 1949—Some Considerations of the Flutter Problems of High Speed Aircraft, E. G. Broadbent, M.A., A.F.R.Ae.S.

Tuesday, 25th October 1949—New Methods of Aircraft Stressing, J. Hadji-Argyris, A.F.R.Ae.S.

Tuesday, 8th November 1949—Resonance in Aerodynamics, R. A. Shaw, M.A., A.F.R.Ae.S.

Tuesday, 22nd November 1949—The Design and Development of Engine Driven Gearboxes, G. W. Bubb, A.F.R.Ae.S.

Tuesday, 6th December 1949—The Design of Tail Pipes for Jet Engines including Re-Heat, J. L. Edwards, B.Sc., A.M.I.Mech.E.

SOCIETY OF BRITISH AIRCRAFT CONSTRUCTORS' EDUCATIONAL GRANTS

The following Candidates were successful in the recent Educational Awards made by the Society of British Aircraft Constructors:—

Mr. Peter Arthur, to be apprenticed to A. V. Roe & Co. Ltd., Manchester.

Mr. Robert Edward Catterwell, to be apprenticed to Vickers-Armstrongs Ltd. (Weybridge Works).

Mr. Alan Duncan England, to be apprenticed to Folland Aircraft Ltd., Hamble.

Mr. Norman Lesueur Filleul, to be apprenticed to Vickers-Armstrongs Ltd. (Supermarine Works).

Mr. David Lomas Hawkes, to be apprenticed to the de Havilland Aircraft Co. Ltd., Hatfield, Herts.

Mr. William Edward Stanbridge, to be apprenticed to the de Havilland Aircraft Co. Ltd., Hatfield, Herts.

BADEN-POWELL MEMORIAL PRIZE

The Baden-Powell Memorial Prize, awarded to the best candidate in the Associate Fellowship Examinations of the Society, has been awarded to Mr. P. J. Wingham, Student Member, following the results of the May 1949 examinations.

PROCEEDINGS OF SECOND AERONAUTICAL CONFERENCE

The Proceedings of the Second Anglo-American Aeronautical Conference, containing the 23 papers read by British and American Lecturers at the Technical Sessions in New York from 24th-26th May 1949, are to be published in one Volume by the Institute of the Aeronautical Sciences. It is hoped that the Proceedings will be ready about January 1950. The price has been fixed by the Institute at 15 dollars (£3 15s. 0d. at the present exchange rate of 4 dollars to the pound).

Copies may be ordered through the Society and it will greatly help both the Society and the Institute if members will place their orders for the Proceedings as quickly as possible.

GRADUATE AND STUDENT SECTION—EXTRAORDINARY GENERAL MEETING

Earlier this year, Council set up a Sub-Committee to investigate the activities of the Graduate and Student Section and to recommend any means of improving the Section. As a result of their findings, Council has decided that the Graduate and Student Section Committee shall become a Committee of Council.

An Extraordinary General Meeting of the Section will be held at the Society, 4 Hamilton Place, on Wednesday, 5th October 1949, at 7.30 p.m.

AGENDA

1. To receive the Hon. Secretary's report of the Section's activities since March 1949.
2. To receive a report on the Council's decisions regarding the future of the Section.
3. To consider any other business.

(Signed) *Michael C. Campion,*
Hon. Secretary, Graduate and Student Section.

18*th August* 1949.

GRADUATE AND STUDENT SECTION—INFORMAL RECEPTION

An Informal Reception and Conversazione for members of the Graduate and Student Section and their friends will be held at the Society, 4 Hamilton Place, W.1, on Friday, 21st October 1949, at 7.30 p.m.

The programme will include a number of short films and an exhibition of part of the Hodgson-Cuthbert Collection. Light refreshments will be served at the

beginning of the evening. A more detailed programme will be issued with the tickets.

The occasion provides an opportunity for members of the Section to introduce their friends to the Society's building, and to meet their friends in the Industry. Ladies will be welcomed.

The number of tickets will be limited, and two tickets only will be allotted to each member of the Section. Application for tickets, which will be 4/- each, should be made to the Hon. Secretary of the Section, M. C. Campion, 6a Mildenhall Road, Clapton, E.5. Cheques and postal orders should be made payable to The Royal Aeronautical Society. Applications will be dealt with in rotation, and should be received by the Hon. Secretary not later than 10th October.

GRADUATE AND STUDENT SECTION

LECTURES

Thursday, 13th October 1949—Address by the President, Sir John S. Buchanan, The Time Scale in Aeronautical Engineering.

Thursday, 27th October 1949—High Lift Devices, R. R. Duddy, A.F.R.Ae.S., of the Royal Aircraft Establishment.

Thursday, 3rd November 1949—Hydraulic Analogy of Compressible Flow—A Substitute for the High Speed Wind Tunnel, H. Ritter, B.Sc.(Eng.), D.I.C. (Graduate), of Imperial College.

Tuesday, 15th November 1949—Visualisation of Air Flow at High Speeds, A. D. Young, A.F.R.Ae.S., of the College of Aeronautics.

Thursday, 8th December 1949—Bonding of Aircraft Materials with Synthetic Adhesives, C. J. Moss, B.Sc., of Aero-Research Ltd.

Lectures will be held in the Library at 4 Hamilton Place, W.1, at 7.30 p.m. The Library will not be open until 7 p.m.

VISIT

Saturday, 19th November 1949—Visit to the National Physical Laboratory, Teddington, Middlesex, at 10 a.m.

Members wishing to take part in this visit, which will be a short tour of several departments, should write to the Assistant Hon. Secretary, D. A. Thurgood, Sunnyside Bungalow, Portsmouth Road, Ripley, Surrey, not later than 1st November 1949.

BRANCH LECTURES—AUTUMN SESSION 1949

COVENTRY BRANCH

Wednesday 21st September 1949—Rocket Propulsion, Air Commodore Dann.

Wednesday 19th October 1949—The London-Sydney Air Route, C. H. Jackson.

Wednesday 16th November 1949—Aircraft Structures, Dr. P. B. Walker, F.R.Ae.S.

Wednesday 14th December 1949—Film Evening on Aircraft Materials.

Meetings are held in the Trinity Hall (near Pool Meadow) Coventry at 7.30 p.m.

LUTON BRANCH

Wednesday 5th October 1949—Film Show.

Wednesday 2nd November 1949—Gas Turbine Development, by a member of the National Gas Turbine Establishment.

Wednesday 23rd November 1949—Aeronautical Brains Trust.

Wednesday 7th December 1949—Role of Aircraft in Future Warfare, Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.

Wednesday 14th December 1949—Annual General Meeting and Presidential Address.

Meetings are usually held at the George Hotel, Luton, at 7.30 p.m.

READING AND DISTRICT BRANCH

Wednesday, 21st September 1949—Servicing and Maintenance of Royal Air Force Aeroplanes—Methods and Problems, Squadron Leader E. A. Harrop, O.B.E., A.F.R.Ae.S.
At the Abbey Gateway, Reading, at 7.30 p.m.

ASSOCIATE FELLOWSHIP EXAMINATION DECEMBER 1949

Candidates are reminded that the December examination will be the last date on which papers will be set in the old syllabus. Papers are still available for the past four years at 2/2 per set (including postage). Entry forms, with fees, must be received by 30th September 1949, but it would help the organisation of the examinations if candidates would inform the Secretary as soon as possible of their intention of taking the examination.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.
When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

JOURNAL BINDING

The prices for binding of Journals are as follows:—

1948 Volume	14s. 6d.	(including packing and postage)
Previous Volumes ..	16s. 0d.	,, ,, ,, ,,
Cases for 1948 Volume	6s. 0d.	,, ,, ,, ,,

Journals should be sent direct to the Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.
Requests for cases, with remittances, should be sent to the Secretary at the Offices of the Society.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Fellow

Ivan Howard Driggs (from Associate Fellow).

Associate Fellows

Thomas William Aynsley (from Student), John Goldfinch, Thomas William Harper, Edwin Lloyd, Maxwell Norman Oxford (from Associate), Herbert Stanley Perry, John Gilbert Russell (from Associate), George Charles Wainwright, Raymond Wilks (from Graduate), Eric Gillard Wilson (from Graduate).

Associates

Carl Agostini, Edward C. Daw, Eric John Dickie, Gordon Stanley Gee (from Graduate), Louis Charles Giles, David Leslie Russell Halliday, Norman Arthur Webb Kitto, Frederick Norville, James Matthew Thom Ormerod.

Graduates

Tom Bromlet Gregory, Ronald Hooper (from Student), Heinrich Rudiger Ilgen, Derek Pym, Thomas Alfred Webb, Cyril Thomas Wheatcroft, Kenneth William Wreghitt.

Students

John Herbert Bibo, David Thomas Miller, Clifford Henry Talbot.

ADDITIONS TO THE LIBRARY

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

A.a.366—The Aerodynamics of Yacht Sails. E. P. Warner. Transactions of the Society of Naval Architects and Marine Engineers. U.S.A. 1925. (V.14.)

B.b.31—The Helicopter: or anything a horse can do. Colonel H. F. Gregory. Allen & Unwin. 1948.

D.c.121—Airports and Air Traffic. John Walter Wood. Coward McCann. 1949.

D.d.34—So you want to enter Civil Aviation. V. E. Mearles. *Daily Mail*. 1948.

E.a.23—Kinematics of Machines. A. F. MacConochie. Pitman & Sons. 1948.

I.b.23—Applied Mathematics. F. D. Murnaghan. John Wiley & Sons. 1948.

K.c.38—Guided Missiles. A. R. Weyl. Temple Press. 1949.

L.k.70—Aviation Medicine: its theory and application. K. G. Bergin. John Wright, Bristol. 1949.

OO.127—Proceedings of the Seventh International Congress of Applied Mechanics 1948. Introduction. 1949.

Q.a.194—Aviation Subject Headings. A. A. Gautreaux and M. Lally. Special Libraries Association, New York. 1949.

Q.c.62—*Daily Mail* Scholarships Guide. J. Truby and L. W. Dorey (Comp.). *Daily Mail*.

R.f.122—Forty Years of Flight: The Romanes Lecture. Lord Brabazon of Tara. Clarendon Press. 1949.

*X.a.60—Newnes Engineer's Reference Book 1949. F. J. Camm (Editor). Newnes. 1949.

*X.c.85—Glossary of Terms used in Aircraft Hydraulic Systems. English—German —French. TPA3. Ministry of Supply. 1948.

Division of Aeronautics, Australia

177—*Note on the solution of differential equation Eigenvalue problems by relaxation methods. F. S. Shaw.*

SM.125—*Buckling of simply supported rectangular plate under direct stresses on all edges. W. H. Wittrick.*

N.A.C.A. Technical Notes

1858—*A review of analytical methods for the treatment of flows with detached shocks. A. Busemann.*

1859—*A method of calculating a stability boundary that defines a region of satisfactory period-damping relationship of the oscillatory mode of motion. L. Sternfield and O. B. Gates, Jr.*

1860—*Theoretical lift and damping in roll of thin sweptback wings of arbitrary taper and sweep at supersonic speeds. Subsonic leading edges and supersonic trailing edges. F. S. Malvestuto, Jr., K. Margolis and H. S. Ribner.*

1861—*One-dimensional flows of an imperfect diatomic gas. A. J. Eggers, Jr.*

1865—*Further experiments on the flow and heat transfer in a heated turbulent air jet. S. Corrsin and M. S. Uneroi.*

1866—*Spin-tunnel investigation to determine the effectiveness of a rocket for spin recovery. A. I. Neihouse.*

1867—*A study of effects of heat treatment and hot-cold-work on properties of low-carbon N.155 alloy. J. W. Freeman, E. E. Reynolds, D. N. Frey and A. E. White.*

1868—*Correlation of pilot opinion of stall warning with flight measurements of various factors which produce the warning. S. B. Anderson.*

1871—*A mathematical theory of plasticity based on the concept of slip. S. B. Batdorf and B. Budiansky.*

1872—*High-lift and lateral control characteristics of an N.A.C.A. 652-215 Semispan wing equipped with plug and retractable ailerons and a full-span slotted flap. J. Fischel and R. D. Vogler.*

1873—*Subsonic two-dimensional-flow conditions near an airfoil determined by static pressures measured at the tunnel wall. B. N. Daley and L. E. Hanna.*

1874—*Analysis of altitude compensation systems for aircraft carburettors. E. W. Otto.*

1876—*Calculation of the aerodynamic loading of flexible wings of arbitrary plan form and stiffness. F. W. Diedrich.*

1889—*Biaxial fatigue strength of 24S-T aluminium Alloy. J. Marin and W. Shelson.*

N.A.C.A. Technical Memoranda

1201—*Rotation in free fall of rectangular wings of elongated shape. Paul Dupleich.*

1213—*Gas motion in a local supersonic region and conditions of potential-flow breakdown. A. A. Nikolskii and G. I. Taganov.*

1224—*Lame's wave functions of the ellipsoid of revolution. J. Meixner.*

1229—*Heat transmission in the boundary layer. L. E. Kalikhman.*

College of Aeronautics, Cranfield

28—*The aerodynamic derivatives with respect to rate of yaw for a delta wing with small dihedral at supersonic speeds. J. H. Hunter-Tod.*

29—*The buckling in compression of panels with square top-hat section stringers. W. S. Hemp and K. H. Griffin.*

30—*The time to achieve peak output with special reference to aircraft production. P. J. Stanley.*

National Research Council of Canada

*Quarterly Bulletin. Report No. ME.*1949(2). 1*st April-*30*th June* 1949.

Royal Institute of Technology, Sweden

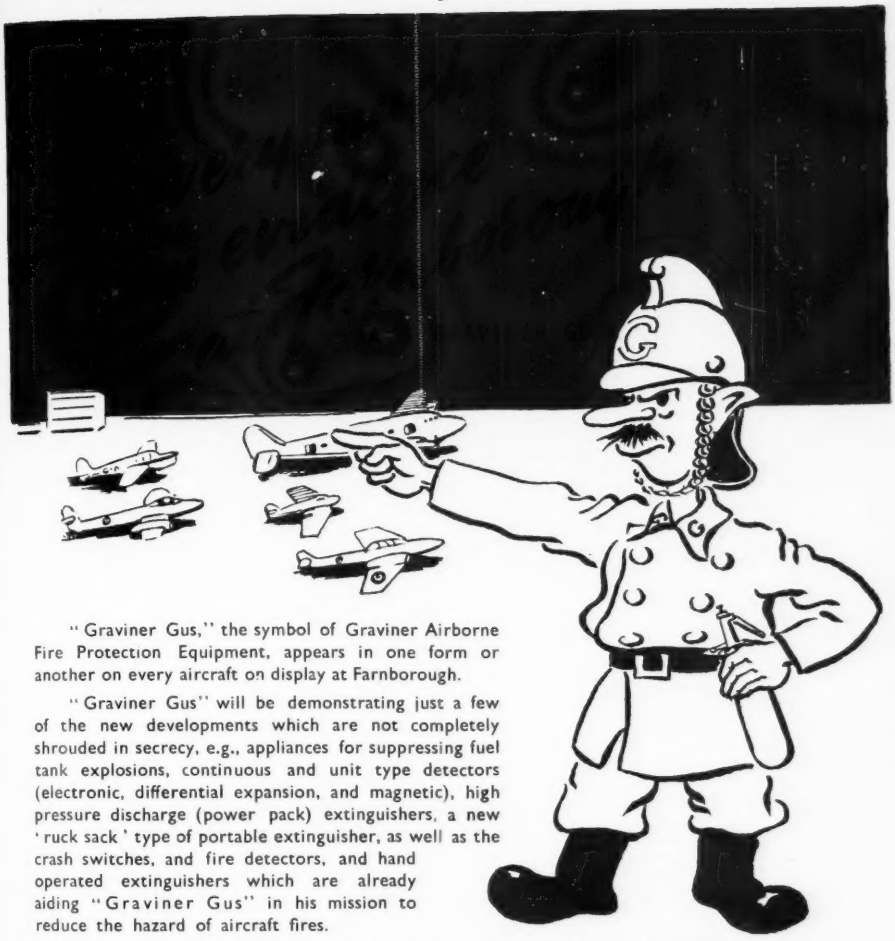
KTH-AERO TN.4—*Three component measurement and flow investigation of plane Delta wings at low speeds and zero yaw. S. B. Berndt.*

KTH-AERO TN.5—*Note on the position of the aerodynamic centre of pointed wings at subsonic speeds. S. B. Berndt.*

Flygtekniska Forsokstalten FFA

Meddelande Nr.26—*Wing sections with minimum drag at supersonic speeds. G. Drougge.*

THE LEWES PRESS (Wightman & Co. Ltd.), Friars Walk, Lewes, Sussex.



"Graviner Gus," the symbol of Graviner Airborne Fire Protection Equipment, appears in one form or another on every aircraft on display at Farnborough.

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DENMARK	Damavia A/S. 2 Poul Ankers Gade, Copenhagen K. *(Tel.: Central 4242).*
EAST AFRICA	Airwork (East Africa) Ltd., P.O. Box 2474, Nairobi, Kenya *(Tel:. Nairobi 3141).*
HOLLAND	Schreiner & Co., 24 Javastraat, The Hague *(Tel.: The Hague 116819).*
INDIA & PAKISTAN	R. K. Dundas (Eastern) Ltd., 133 Esplanade Road, Bombay *(Tel.: 270245).*
ITALY	Greemham & Co. Ltd., Via Rivoli 2, Milan *(Tel.: Milan 16.134).*
SWEDEN	Salen & Wicander A.B., Stymansgatan 4, Stockholm *(Tel.: 679340).*
U.S.A.	Simmonds Aerocessories Inc., Tarrytown, New York *(Tel.: Tarrytown 4-3600).*

V.I.P.'S ABOARD. A Saunders-Roe "Princess" (SR/45) picks up her escort of SR/A1 fighter flying bo

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